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STI TECHNICAL REPORT NO. 1073-1

THE CONCEPTUAL DESIGN OF A
SAFETY MARGIN SYSTEM FOR THE AUGMENTOR WING
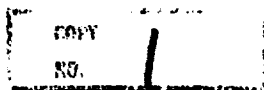
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Robert L. Stapleford

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Figure 1

DEFINITION OF A SAFETY MARGIN SYSTEM

The functions of the safety margin system are to:

- Provide an indication to the pilot of margins between the current and hazardous vehicle states

- Indicate to the pilot appropriate corrective action when a hazardous vehicle state is encountered

Conversely, the system is not concerned with:

- Trajectory monitoring

- Monitoring the status of on-board equipment, such as the AFCS

Hazardous vehicle states include:

- Those for which a large gust or wind shear could cause a stall, other loss of control, or entry into a region of unknown aerodynamic characteristics

- Those which do not provide adequate performance and maneuverability for normal and emergency maneuvers

- Those which do not provide adequate performance and control for recovery from an engine or AFCS failure

An important part of the project was to more thoroughly define various possible hazardous states and the associated margin requirements. This effort resulted in a list of nine safety margin components which should collectively provide adequate protection for any powered-lift aircraft. While, in theory, all nine might have to be included in a safety margin system, for any particular aircraft only a few should be critical and therefore have to be included. In fact, when this concept was applied to the Augmentor Wing we found that most of the components were unimportant for this aircraft. This subject is discussed in Section II, which describes each of the nine components and how they apply to the Augmentor Wing in particular. The conclusion from this section is that the critical component is lift margin and that lift margin could also be used as the flight reference for the Augmentor Wing.

Section III is a discussion of using lift margin as both the flight reference and a safety margin monitor for the Augmentor Wing. It describes the key features of such a system as well as indicating unresolved problems which could not be addressed in this project.

Section IV presents a summary of the results of this investigation and the plans for the recommended follow-on program.

SECTION II

SAFETY MARGIN COMPONENTS

A. GENERAL DISCUSSION

Our initial effort was concerned with safety margins for powered-lift aircraft in general. For powered-lift aircraft there are a number of different potential hazards which must be protected against. Consideration of the various hazards led to the list of nine safety margin components. These concepts were then applied to the Augmentor Wing during slow speed operation, such as landing approach. To do this required data on the lift/drag characteristics of the Augmentor Wing for various configurations.

These data were obtained from a digital computer program developed by Luigi Cicolani of NASA/ARC. The data were generated as a set of lift versus drag plots, which are included in the Appendix. The plots were done for sea-level and a standard day, and, for convenience, were normalized to an aircraft weight of 40,000 lb. The plots are for four nozzle settings (6, 40, 75, and 104 deg) and six combinations of airspeed and flap setting: 65 deg flap and 55, 65, and 75 kt; 50 deg flap and 65, 75, and 90 kt.

Subsection B is a description of each of the nine safety margin components. For each there is a general discussion followed by its applicability to the Augmentor Wing in particular. The key conclusions are summarized in Subsection C.

B. SPECIFIC COMPONENTS

1. Lift Margin

For safe operation, the pilot must always have the ability to make a fairly rapid flight path change. In other words, he must have some maneuver capability. One of the fastest and most instinctive ways to maneuver the

airplane is by increasing the angle of attack. Lift margin (LM) provides this maneuver capability. It is defined by:

$$LM = \frac{L_{max} - L}{W}$$

where   W   =   aircraft weight

            L   =   current lift including all thrust contributions

            L_{max} =   maximum lift which could be obtained by increasing angle of attack while maintaining the current value of all other aircraft parameters such as airspeed, thrust, flap, and nozzle.

The concept of applying a lift margin to the Augmentor Wing was first suggested in Reference 1. The concept of lift margin as a possible safety monitor for the pilot has since been fostered by Gordon Hardy of NASA/ARC.

A lift margin insures the pilot a certain amount of maneuverability. The next question is how to select appropriate limits. For this we can consider conventional aircraft experience. A conventional jet transport operating at the lower airspeed limit of $1.3\ V_s$ has a lift margin of roughly 0.5 g. The maximum load factor is not 1.3^2 because V_s is somewhat less than a true 1 g stall speed. This suggests a trim limit of 0.5 for conventional aircraft or powered-lift aircraft when not operating in a powered-lift mode, such as the Augmentor Wing with the flaps up. When operating in a powered-lift mode, the pilot can also directly increase lift by adding power in addition to increasing angle of attack. Therefore, a lower limit might be acceptable in the powered-lift mode. A trim limit of 0.4 g is suggested by Augmentor Wing flight experience. The suggested trim limits for the Augmentor Wing are therefore:

            LM $\geq$ 0.5 g flaps up

            LM $\geq$ 0.4 g flaps down

2. Climb Capability

In addition to a lift margin, a pilot must also have the ability to change drag. From a safety viewpoint, he must be able to either accelerate

or equivalently to decrease his rate of descent. The ability to decelerate, or steepen the flight path, is also necessary to accomplish the task but does not pose a safety problem. The ability to rapidly reduce the rate of descent is an important safety factor. It provides the pilot the ability to compensate for wind shears or gusts and also buys him time to reconfigure the aircraft for a go-around.

A climb, or $\Delta\gamma$, capability implies that the pilot is not using the maximum available power. Thus the available $\Delta\gamma$ is directly related to the difference between the current power setting and the maximum available for the particular configuration and ambient conditions. There is some question as how to precisely define a $\Delta\gamma$ requirement but the most logical choice seems to be to use one based on steady state conditions. Even so, the effects of the configuration must be considered. Figure 2 shows how nozzle deflection affects the relationship between $\Delta\gamma$ and power for the Augmentor Wing.

Figure 2 illustrates another point. The $\Delta\gamma$ which can be achieved depends on what flight reference changes occur at the same time. The pilot would get a different change in flight path angle if, when going to full power, he maintained airspeed, lift margin, or angle of attack. One choice is to require that the pilot maintain his flight reference, whatever that is, in the maneuver. However, at least in theory, holding the flight reference could require an acceleration to a higher airspeed. It may be dangerous to require this acceleration to get the climb capability because there may not be time to accelerate. Therefore, we propose to define $\Delta\gamma$ as the lesser of the trim flight path change that can be accomplished by going to maximum available power while either maintaining airspeed or flight reference.

The amount of $\Delta\gamma$ capability required was investigated in the NASA/FAA STOL Airworthiness Program. Those simulations (References 2 and 3) concluded that a capability on the order of 3 - 4 deg about the trim point was required for safe operation. This limit would seem applicable here.

3. Maximum Flight Path Angle

While Item 2 discussed the capability to change flight path angle, it did not restrict the flight path angle that could be achieved without
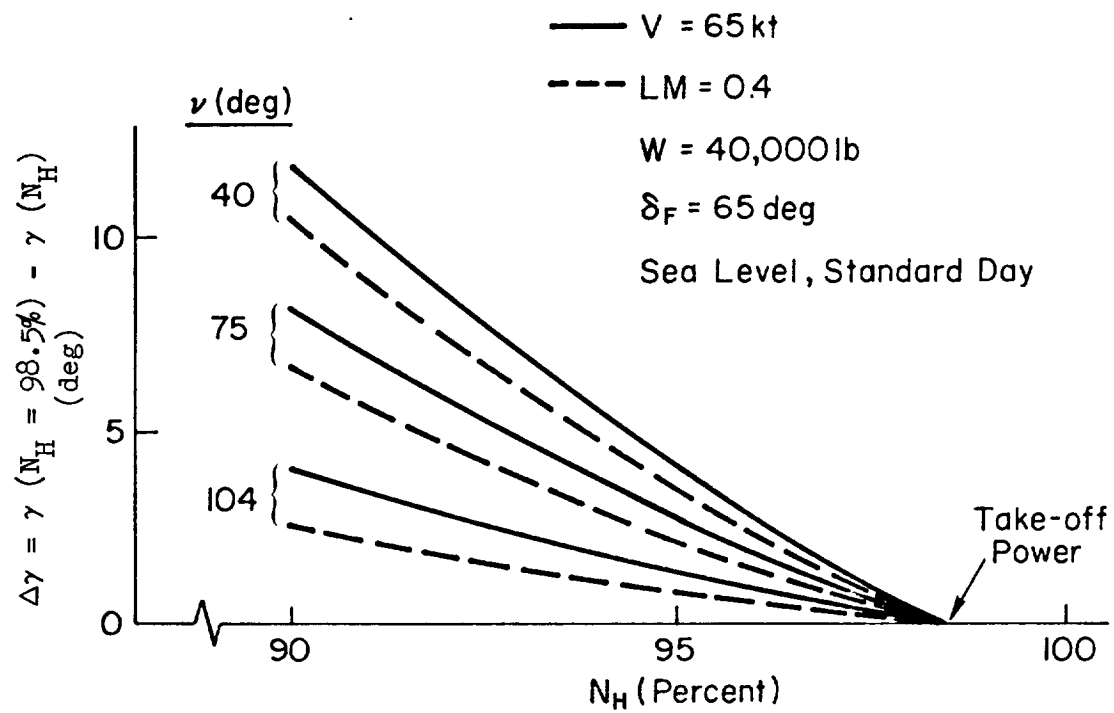
Figure 2. Augmentor Wing Climb Margin

reconfiguring the aircraft. If the aircraft were descending with γ = -10 deg and had $\Delta\gamma$ capability of 4 deg, the best the pilot could do without reconfiguring would be to shallow the angle to -6 deg. This could be a hazardous situation. In fact, the Powered-Lift Standards Development Working Group (PLSDWG) agreed that the airworthiness requirements should include the ability to achieve level flight without a configuration change, as well as a $\Delta\gamma$ = $\pm$ 4 deg requirement (Reference 4). Of course, a γ_{max} requirement should be a function of the flight phase with a positive requirement during cruise and something on the order of zero for landing approach. The whole purpose of this requirement is to insure the pilot can get to a relatively safe flight path in a short time. It assumes that a configuration change may take too long to accomplish.

This particular requirement does not seem necessary for the Augmentor Wing because the pilot has an additional control, the nozzles, which can be very rapidly applied to assist him in a go-around maneuver. Even though he may be in a condition where full power will not get him to level flight, rotating the nozzles can very quickly get him to that condition (see the γ - V curves of Figure 3). Therefore we conclude that this criterion need not be incorporated into a safety margin system for the Augmentor Wing.

4. Angle of Attack Margin From α_{max}

The tentative airworthiness requirements established by the PLSDWG (Reference 4) include the requirement for an angle of attack margin from α_{max}. This margin is intended to provide protection from vertical gusts and from pilot abuses of attitude. Any potentially hazardous condition is, by definition, associated with α_{max}. The PLSDWG definition is that α_{max} is the smallest angle of attack which results in one of the following:

    a) A temporary loss of control about any axes

    b) An abrupt change in pitching moment or normal acceleration

    c) Excessive buffetting
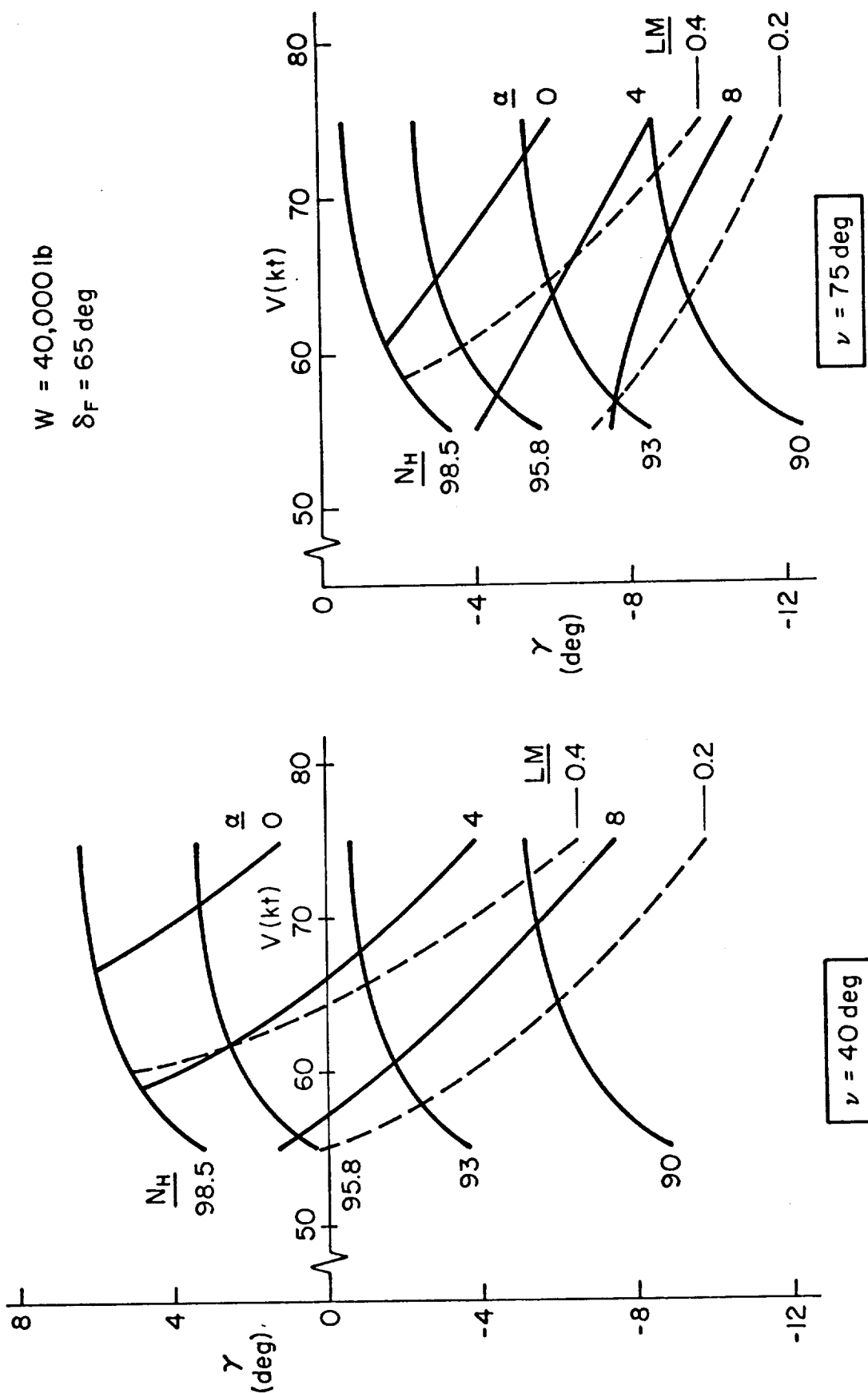
    d) Maximum angle of attack demonstrated in flight tests.

Figure 3. Sample γ–V Curves for the Augmentor Wing

In setting the required angle of attack margin the PLSDWG decided to do it on the basis of the vertical gust which would take the aircraft to α_{max}. Examination of data for current jet transports showed a gust margin of roughly 20 kt and this value was selected by the PLSDWG. Thus, their requirement is $\alpha_{max} - \alpha > \sin^{-1} \frac{20}{V}$ where V is the approach speed in kt.

For application to the Augmentor Wing the question is whether the angle of attack margin is more restrictive than the lift margin requirement. The angle of attack margin criterion is somewhat difficult to apply to the Augmentor Wing because α_{max} for it has not been defined. We are not aware of any high angle of attack control problems. We could make the very conservative assumption that α_{max} will be the angle of attack for maximum lift. However, even this presents a problem as that angle of attack has not been firmly established.

As a rough check, we examined our computer model data for a lift margin of 0.4 g with 65 deg flaps and 75 deg nozzle. With a conservative estimate of $\alpha_{max} = 20$ deg, the computed vertical gust margin is 18 kt for approach speeds between 60 and 75 kt. Since this is close to the PLSDWG requirement, even using a conservative estimate for α_{max}, we feel the angle of attack margin is not required for the Augmentor Wing if lift margin is used.

5. Speed Margin From V_{min}

The PLSDWG also requires an airspeed margin from the minimum airspeed, V_{min}. This is to provide protection from wind shears, horizontal gusts, and pilot abuses of the flight reference. V_{min} is determined by one or more of the following:

·a) Attainment of an airspeed corresponding to α_{max}, steady state

b) Attainment of an airspeed which, under steady state conditions, would result in an excessive rate of descent

c) Maximum lift coefficient

d) Minimum airspeed demonstrated in flight test.

The PLSDWG margin requirements are in two parts. The first is that the approach speed be at least the greater of $1.15 \ V_{min_A}$ and $V_{min_A} + 10$ kt, where V_{min_A} is the value of V_{min} for the approach power setting. In the second part of the requirement, approach speed has to be at least the greater of $1.3 \ V_{min}$ and $V_{min} + 20$ kt, where V_{min} is that for maximum authorized power.

The speed margins are directly related to the lift margins. If the maximum lift coefficient for a given power setting were independent of speed, then the ratio of V to V_{min_A} would be given by:

$$\frac{V}{V_{min_A}} = \sqrt{1 + LM}$$

For a lift margin of 0.4, this would give a speed of $1.18 \ V_{min_A}$. However, for the Augmentor Wing and most powered-lift aircraft, the maximum C_L increases as speed is decreased because the blowing coefficient increases (for a fixed power setting). Consequently, a given lift margin gives an even bigger speed margin. For example, the minimum speed for $N_H = 90\%$, 65 deg flaps, and 75 deg nozzle was estimated at 54 kt. To get a lift margin of 0.4 g for that same condition the speed must be increased to approximately 71.5 kt. This provides a speed margin of 17.5 kt or $0.32 \ V_{min_A}$. Thus speed margin seems to be a less restrictive requirement than lift margin for the Augmentor Wing.

6. Speed Margin From V_{MC}

V_{MC} is the minimum control speed for an engine failure. The purpose of this margin is to insure the pilot is not flying so slow he cannot recover from the loss of an engine. The PLSDWG took a slightly different approach to this problem than that used for conventional transports in FAR PART 25.

FAR PART 25 defines a minimum control speed and then requires some margin above that speed. The PLSDWG proposed using a more restrictive definition of V_{MC} but not requiring any margins.

For the Augmentor Wing, a V_{MC} margin is not a limiting requirement. V_{MC} (FAR PART 25 definition) occurs near or below the stall speed so that the V_{min} margin requirements would be more restrictive. As pointed out just previously, those requirements are, in turn, less restrictive than the lift margin requirement.

7. Speed Margin for FCS Failure

While we have no specific examples, in principle there could be a minimum airspeed required for safe recovery from a critical failure of the flight control system (FCS). This concept is a direct extention of the requirement for the V_{MC} margin to protect for engine failures. While this requirement might be critical for some aircraft it is not for the Augmentor Wing. To our knowledge there are no such speed restrictions on the Augmentor Wing.

8. Flight Control System Saturation

Some powered-lift aircraft (e.g., Boeing YC-14) will have an FCS which will greatly alter the aircraft responses to the movements of the pilot's controls. If such a system should saturate, the aircraft dynamics, as seen by the pilot, could change drastically enough to present a safety problem. This item is intended to protect against such possibilities when they exist. The seriousness of the problem would depend strongly on the specific details of the FCS and the basic characteristics of the aircraft. To our knowledge there are no such problems on the Augmentor Wing and this item need not be considered.

9. Structural Limits

A structural limit common to all transport aircraft is the flap placard speeds. This problem is largely unrelated to the other safety margin components discussed here and should be handled separately. Furthermore,

it would seem that the monitoring provisions in the Augmentor Wing and other aircraft are currently satisfactory and additional monitoring is not required.

Another structural limit for the Augmentor Wing is the maximum power when the nozzles are deflected more than 36 deg. This limit is takeoff power, 98.5% on a standard day, at sea level. This then places one limit on the maximum power that is available and should be considered in the $\Delta\gamma$ margin since that margin must include consideration of all power limits. Providing a $\Delta\gamma$ margin will take care of this structural problem.

C. SUMMARY

The major conclusion from the above is that a safety margin system for the Augmentor Wing needs two components: lift and $\Delta\gamma$ margins. Of these two, lift margin is the more important as it provides protection from gusts and wind shears and provides the margin from stall. The $\Delta\gamma$ component can provide the pilot an indication of how much additional thrust he has available in terms of the flight path change he can make. Adding both elements to the aircraft's displays would certainly increase pilot workload, therefore it seems quite logical to consider the possibility of using lift margin as the flight reference.

This may have an additional benefit in that neither airspeed nor angle of attack have been completely satisfactory as a flight reference. The major problem with using airspeed is that low power settings can result in very small margins. With angle of attack as a flight reference, the margins are less sensitive to power but airspeed excursions can be quite large and there is a pilot control problem in trying to regulate angle of attack. The angle of attack and flight path responses to attitude and power are quite highly coupled. Furthermore the coupling is adverse in that adding power requires the pilot to pitch nose down to maintain the angle of attack.

The use of lift margin as the flight reference as well as a safety margin monitor is discussed more fully in Section III.

SECTION III

LIFT MARGIN AS FLIGHT REFERENCE AND SAFETY MARGIN MONITOR

This section will discuss advantages, disadvantages, and problems of using lift margin as both the flight reference and a safety margin monitor for the Augmentor Wing. Frequent reference will be made to the γ - V plots shown in Figure 3. These were derived from the lift/drag curves given in the Appendix. Since those curves were available only at speeds of 55, 65, and 75 kt, the γ - V plots are based on interpolation for other speeds and are, therefore, subject to some inaccuracies.

Subsection A describes some of the key features which would be obtained with this system. Subsection B discusses some of the unresolved problems which must be solved before such a system could actually be implemented.

A. KEY FEATURES

The primary reason for proposing lift margin as both the flight reference and a safety margin monitor is to reduce the pilot workload by reducing the number of displayed variables to be monitored. Lift margin could assume the role of airspeed in a conventional aircraft in that it provides both a reference and an indication of safety margins.

As a flight reference, lift margin is a compromise between angle of attack and airspeed as can be seen in Figure 3. The major effects are:

1) The constant lift margin requires smaller speed
   changes than for constant angle of attack as flight
   path changes are made

2) For the approach configuration, the maximum flight
   path angle for a constant lift margin is greater than
   that for a constant angle of attack, but less than
   that for constant airspeed

3) The control coupling for lift margin is not as
    adverse as it is for constant angle of attack in that
    smaller pitch down will be required when adding
    power. For constant airspeed, the coupling is even
    less adverse and may be proverse, that is, pitch up
    when adding power.

A flight reference similar to lift margin has already been tested in
the simulator as part of the NASA/FAA STOL Airworthiness Program. The
STOL-X configuration, Reference 3, had a flight reference which was angle
of attack plus a thrust correction. That flight reference was quite
satisfactory and did not present any serious piloting problems.

During the landing approach the STOL piloting technique should still be
appropriate, that is, pilot should control flight path with power and flight
reference with pitch. Furthermore, one would expect a low frequency cross-
feed from the power, or $\Delta\gamma$ margin, to the nozzle. If the pilot found his
average power setting was too high, or $\Delta\gamma$ was too low, he could decrease
the nozzle deflection which would allow him to reduce power. The initial
nozzle setting would be selected on the basis of aircraft weight, glide
slope angle, reported winds, and ambient temperature.

For a flare with attitude, one would expect more consistent performance
with lift margin as the flight reference than with airspeed. When the flight
reference is airspeed and one enters the flare with a high power setting,
there is a tendency to float. On the other hand, coming into the flare
with a low power setting can cause a hard landing. Flying with constant
lift margin should make the flare more repeatable since you would be starting
the flare at a similar place on the lift/drag curve each time. The relative
advantages of angle of attack and lift margin in this respect are unknown.

Another advantage of the lift margin concept is that recovery from a
low margin is so simple that a recovery display should not be required. If
lift margin is low, pitch over or add power. If lift margin is also the
flight reference, this recovery procedure is essentially what the pilot
would be doing more or less continuously during the approach as he controlled
flight reference.

While the pilot should be able to utilize lift margin as his flight reference, the existing STOLAND automatic system and flight director use airspeed as the flight reference. When operating with either of these systems, the pilot could use lift margin strictly as a safety margin monitor. He could largely eliminate his angle of attack and airspeed monitoring and concentrate on the lift margin.

B. UNRESOLVED PROBLEMS

While the system described here shows a great deal of promise, there are certain unresolved problems we have not had the time or funds to attack. One of these is the dynamics of the pilot control task with lift margin as the flight reference. Potential manual control problems certainly need to be investigated, especially as regards to cross-coupling between flight reference and flight path control. It may be that adequate performance and pilot workload cannot be achieved without an appropriate flight director.

Another problem which needs to be addressed is how to display lift and $\Delta\gamma$ margins to the pilot. One concept would be to use dial instruments for both, with color coding for safe, cautious, and dangerous regions. A movable bug would also allow the pilot to make some adjustments for the existing wind and turbulence conditions, just as he does with his airspeed reference in a conventional aircraft.

Regardless of how the data is displayed, the question of appropriate limits for lift and $\Delta\gamma$ margins needs to be answered. There is also a question about the need for additional pilot alerting devices, such as stick shakers, lights, or horns.

One of the most serious problems with lift margin is what happens in the event of a system failure. A failure of the lift margin indicator is analogous to the failure of the airspeed indicator and could be just as disastrous. Unfortunately, the lift margin indicator is a much more complicated system. It will require several sensors to obtain the necessary input data and a digital computer to process that data. Consequently, one

would expect a much higher failure rate than for a simple airspeed indicator. The basic problem is that the system could fail without the pilot being aware of the failure and this could lead to disaster. Therefore it would probably be necessary to have a redundant mechanization for the lift margin system. A dual, self-checking mechanization might be adequate. This would at least warn the pilot when a failure occurred.

SECTION IV

SUMMARY AND RECOMMENDATIONS FOR ADDITIONAL RESEARCH

Subsection A is a brief review of the proposed safety margin system for the Augmentor Wing. Subsection B describes areas of additional research which should be conducted to prove the feasibility of this system and to work out design details. Subsection C describes a recommended follow-on program which would take the concept evaluation through a simulator study.

A. PROPOSED SYSTEM

The proposed system uses lift margin as both a flight reference and the primary safety margin monitor. It would also include a display of $\Delta\gamma$ capability as an additional safety margin component. Such a system has great potential for reducing pilot workload and improving safety. Furthermore, the concept should be applicable to most, if not all, powered-lift aircraft. The key idea is to replace the use of airspeed in a conventional aircraft with lift margin in a powered-lift one. This might eliminate many of the piloting difficulties which are associated with powered-lift aircraft.

B. AREAS FOR ADDITIONAL RESEARCH

1. Dynamic Characteristics

Pilot control of lift margin and flight path with attitude and power is a control task that has not yet been analyzed. The dynamic characteristics need to be carefully examined for potential piloting difficulties.

2. Flight Director Design

While it may be possible to fly lift margin and flight path on raw data, a flight director would certainly reduce the pilot workload. Although the

problems in designing a flight director for such a system are unknown, there is no reason to suspect that the job would be much more difficult than when airspeed is the flight reference.

3. Display Formats

Both optimum and acceptable methods of displaying lift and $\Delta\gamma$ margins should be determined. This can best be done in a ground-based simulator experiment which is carefully planned to fully evaluate the candidate displays.

4. Alerting Devices

In addition to the margin displays, there may be a need to have additional alerting devices such as stick shakers, pushers, lights, horns, etc. The need for such devices needs to be examined and this could also be done on the simulator.

5. Numerical Limits

While we can probably come fairly close in establishing appropriate limits for lift and $\Delta\gamma$ margins, these need to be verified. Limits should be established both for target or trim conditions as well as transient conditions.

6. Redundancy Requirements

A failure of the lift margin indicator with no warning to the pilot is probably very hazardous as it could be very difficult for the pilot to detect the failure from his other instruments. This needs to be verified and, if true, the next step is to determine if it is satisfactory to just indicate that a failure has occurred. A dual redundant system could provide self-checking so the pilot would know that a failure has occurred but he would still lose his lift margin indicator. Whether or not he could safely recover from this situation has to be investigated. The problem with the

$\Delta\gamma$ margin is much less serious since the pilot has a cross-check through his normal engine instruments.

7. Mechanization Possibilities

There are several possibilities for mechanizing the proposed system. Since it will probably have to be redundant, it is especially important to investigate any simple, cheap, and reliable mechanization schemes. The basic problem is that lift and $\Delta\gamma$ margins are both complex functions of a large number of parameters.

8. Refinement of High α Data

Prior to flight testing such a system it will be necessary to review the high angle of attack flight test data to make sure it is compatible with the computer models of the Augmentor Wing. Before flight testing such a system the best available data should be used to provide the most accurate values of lift margin. Even for a simulator evaluation, one must be careful to check that the simulator model of the aircraft and the math model used to develop the system agree even at high angles of attack. These two may not agree since they may have been developed at different times or for different purposes.

C. RECOMMENDED FOLLOW-ON PROGRAM

A follow-on program is needed to verify the safety margin concepts presented here and to work out some of the system details. The program should include additional analyses and a simulator evaluation. The program plan given below includes a two part simulation. Splitting the simulation effort into two parts, with a short break between, allows more iterations on the system design features. During the break the results of the first phase simulation would be analyzed. System modifications to correct problems or deficiencies could be designed and checked out. These would be evaluated in the second phase simulation.

The following is a list of work items for a minimum cost program to substantiate the value of the proposed safety margin system. Included are man hours for each task and overall cost. This program would consider only the landing approach flight phase.

1. Basic Data   300 man-hr

        Check math model against STOLAND 8400 simulation

        Make γ - V plots for:

            δ_F = 50, 65 deg

            Various v from 6 - 104 deg

            W = 40,000 lb

            Sea level, standard day

        Prepare "flight manual" charts, e.g., nozzle settings for combinations of wind and glide slope angle

2. Pilot/Vehicle Analysis   200 man-hr

        For 4 - 5 flight conditions, obtain attitude-constrained stability derivatives including partial derivatives of lift margin with α, V, and N_H

        Compute appropriate transfer functions

        Analyze manual control task ($\epsilon_{GS} \longrightarrow N_H$, LM $\longrightarrow \theta$)

3. Prepare for Phase I Simulation   250 man-hr

        Prepare test plan

        Specify software modifications for:

            $\Delta\gamma$ margin (lift margin is already programmed)
            Data collection
            Additional inputs, e.g., discrete gusts or wind shears

Specify display formats for $\Delta\gamma$ and LM

Check-out simulator

4. Conduct Phase I Simulation   200 man-hr

Simulation would require 1 - 2 NASA pilots
and would last for two weeks

Test conditions would include:

Various wind conditions and profiles

Severe wind shears or discrete gusts

Operation in the manual, flight director,
and automatic modes

Failures of the safety margin system

5. Review Phase I Results and Plan Phase II Simulation

                                            200 man-hr

Review Phase I results

Revise safety margin system to correct deficiencies

Plan Phase II test

Check-out simulator

6. Conduct Phase II Simulation   300 man-hr

Simulation would require 3 - 4 NASA pilots
and last for three weeks

Test conditions would be similar to Phase I

7. Plan Flight Test Program   100 man-hr

Prepare a program plan for flight test evaluation
of the safety margin system in the Augmentor Wing,

including estimates of program cost and
required flight hours

8. Reporting   350 man-hr

    Prepare final report and oral presentation

    Prepare interim project briefings upon
    completion of work items 2, 3, and 5.

                              TOTAL   1900 man-hr

        Estimated Cost (Items 1 - 8) $55,100

In addition to the above minimum program, the following work items
are also recommended. These work items are necessary to more fully
evaluate the practical potential of the proposed safety margin system.
The following includes manpower and cost estimates for each item. Each
estimate includes the additional documentation for that particular effort.

9. Flight Director Design

    Design a flight director for use during final approach
    which provides attitude (θ and φ) and power commands to
    control ILS errors and lift margin

    Evaluate flight director in simulator. This would
    require one week extensions to both Phase I and II
    simulations

        Estimated manpower: 500 man-hr

        Estimated cost: $14,500

10. Flight Envelope Expansion

Expand the analyses (Item 1 and 2) to cover the complete flight envelope of the Augmentor Wing, i.e., include lower flap settings and higher airspeeds.

Expand the simulator tests to also cover the complete flight envelope. This would require one week extensions to both Phase I and II simulations.

Estimated manpower: 800 man-hr

Estimated cost: $23,200

11. Mechanization

Investigate alternative methods of mechanizing the safety margin system (measurement and display of lift and $\Delta\gamma$ margins)

Perform preliminary trade-off study of various candidate mechanizations

Estimated manpower: 500 man-hr

Estimated cost: $14,500

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APPENDIX

LIFT/DRAG PLOTS

Plots of lift versus drag for various combinations of flap, nozzle, and airspeed are presented. Both lift and drag include all thrust contributions and are normalized with respect to a weight of 40,000 lb. The plots were made for lines of constant engine RPM, N_H, and fuselage angle of attack, α. The values of α were chosen to include a wide operating region, especially beyond $C_{L_{max}}$. The values of N_H were chosen to include minimum to maximum power with specific critical power setting, that is:

$$N_H = 101.5\% = \text{Emergency power, 2.5 minute time limit}$$

$$N_H = 98.5\% = \text{Takeoff power, 15 minute time limit}$$

$$N_H = 95.8\% = \text{Maximum continuous power}$$

$$N_H = 84\% = \text{Effectively power off.}$$

All plots are for sea level and standard day conditions. The specific plots are identified below:

FIGURE	AIRSPEED	FLAP	NOZZLE
A1 - A4	55 kt	65 deg	6, 40, 75, 104 deg
A5 - A8	65 kt	65 deg	6, 40, 75, 104 deg
A9 - A12	75 kt	65 deg	6, 40, 75, 104 deg
A13 - A16	65 kt	50 deg	6, 40, 75, 104 deg
A17 - A20	75 kt	50 deg	6, 40, 75, 104 deg
A21 - A23	90 kt	50 deg	6, 40, 75 deg

Figure A-1

V = 55 KT
F = 65 deg
U = 40 deg
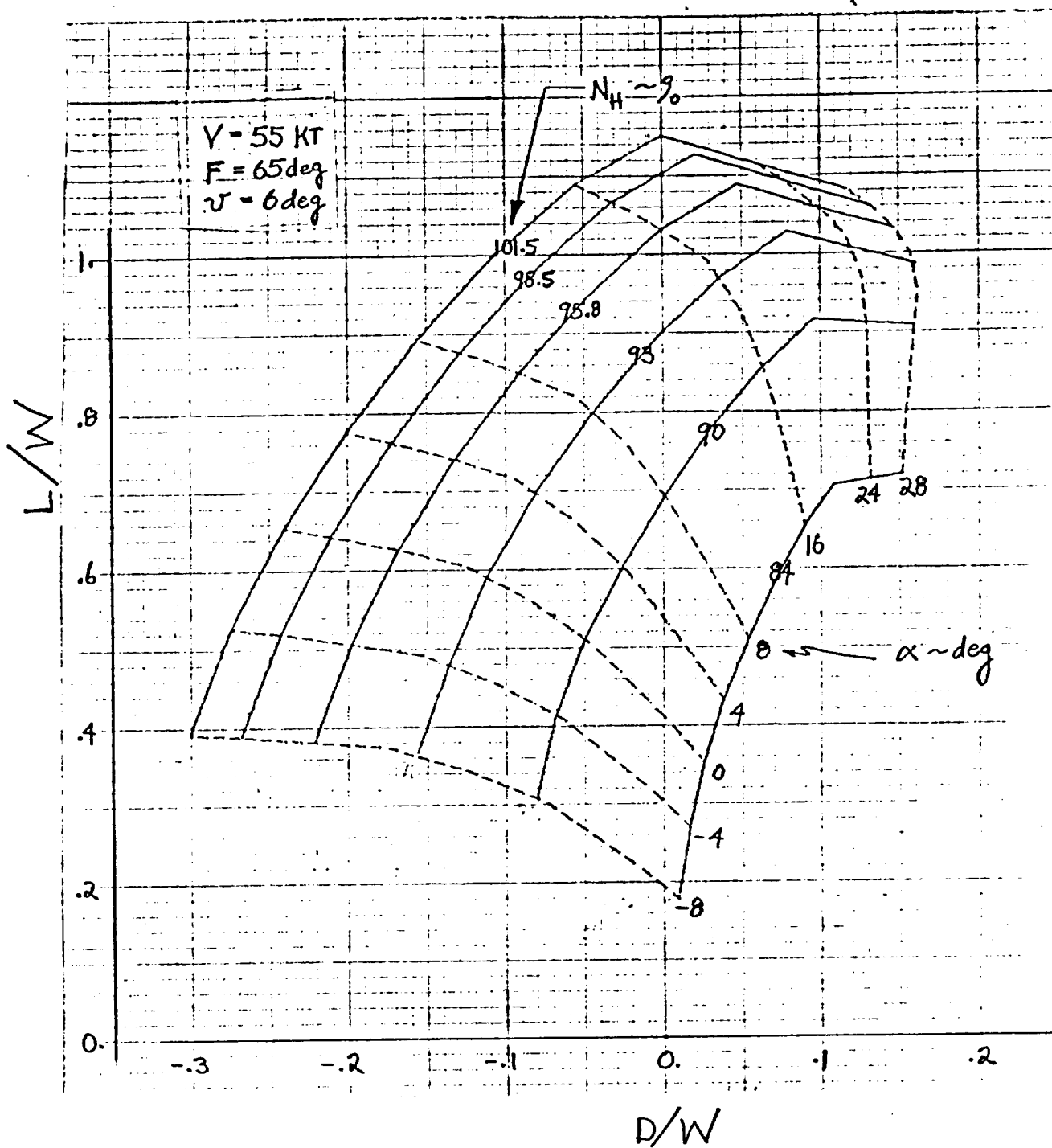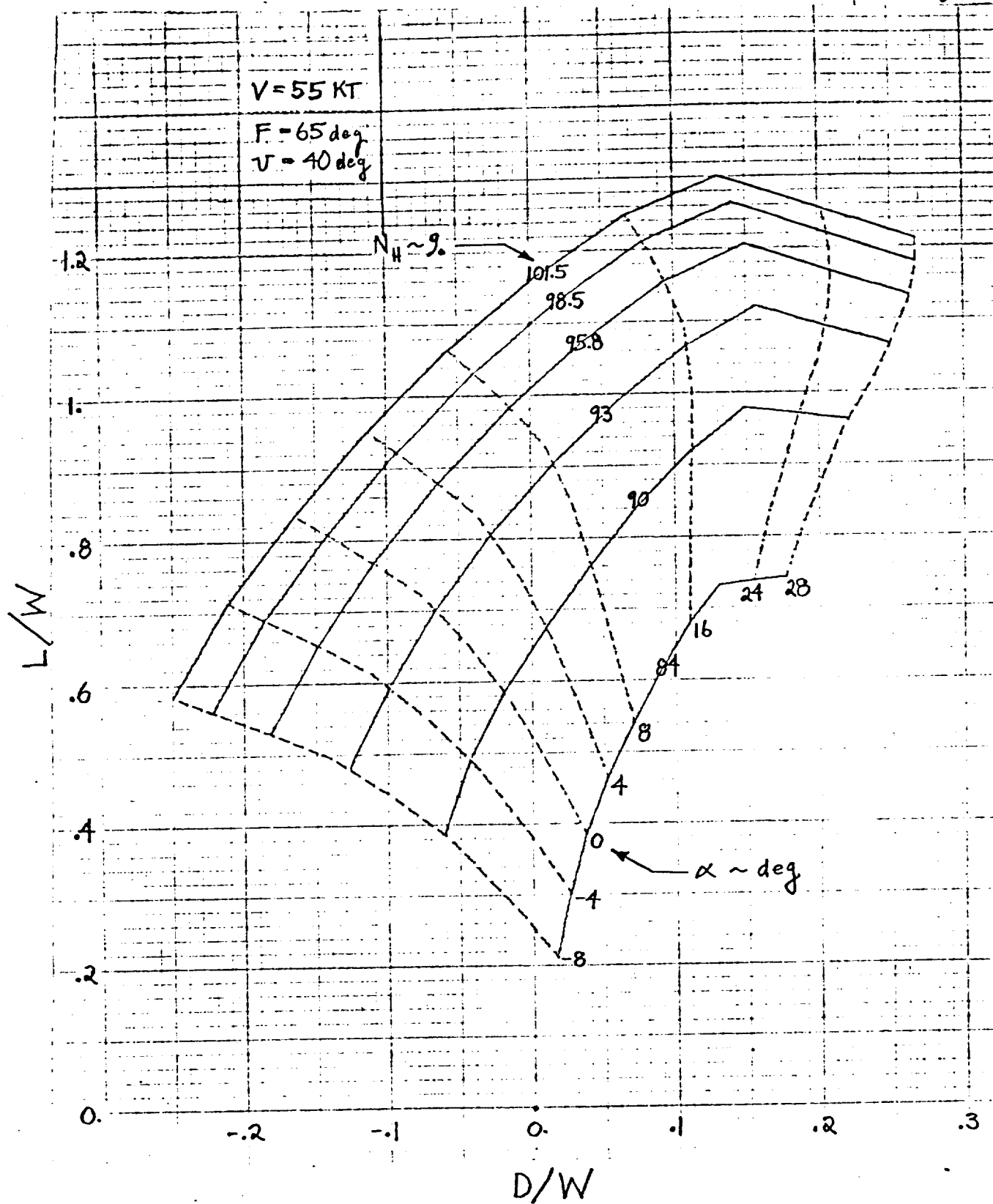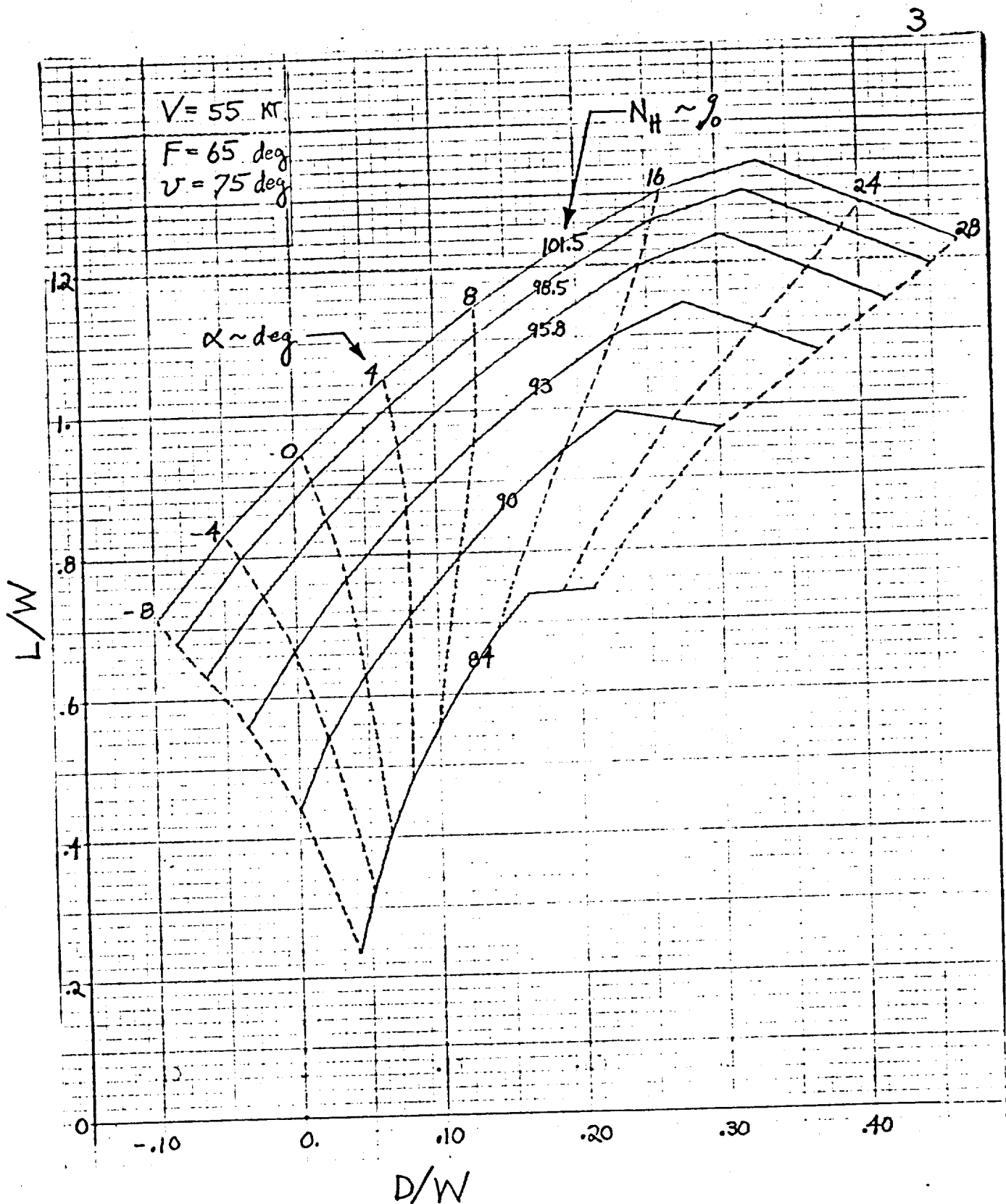
Figure A-2

Figure A-3
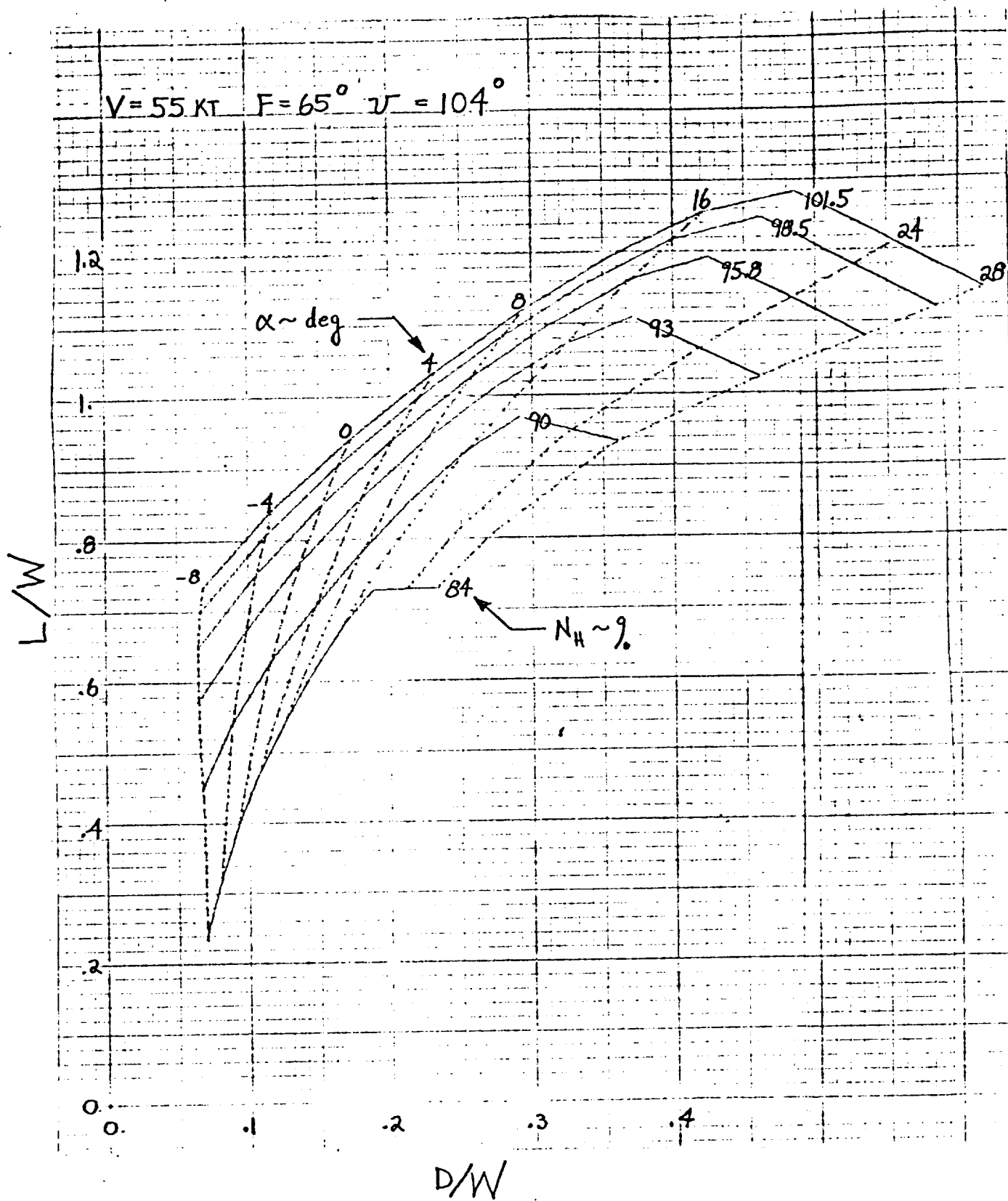
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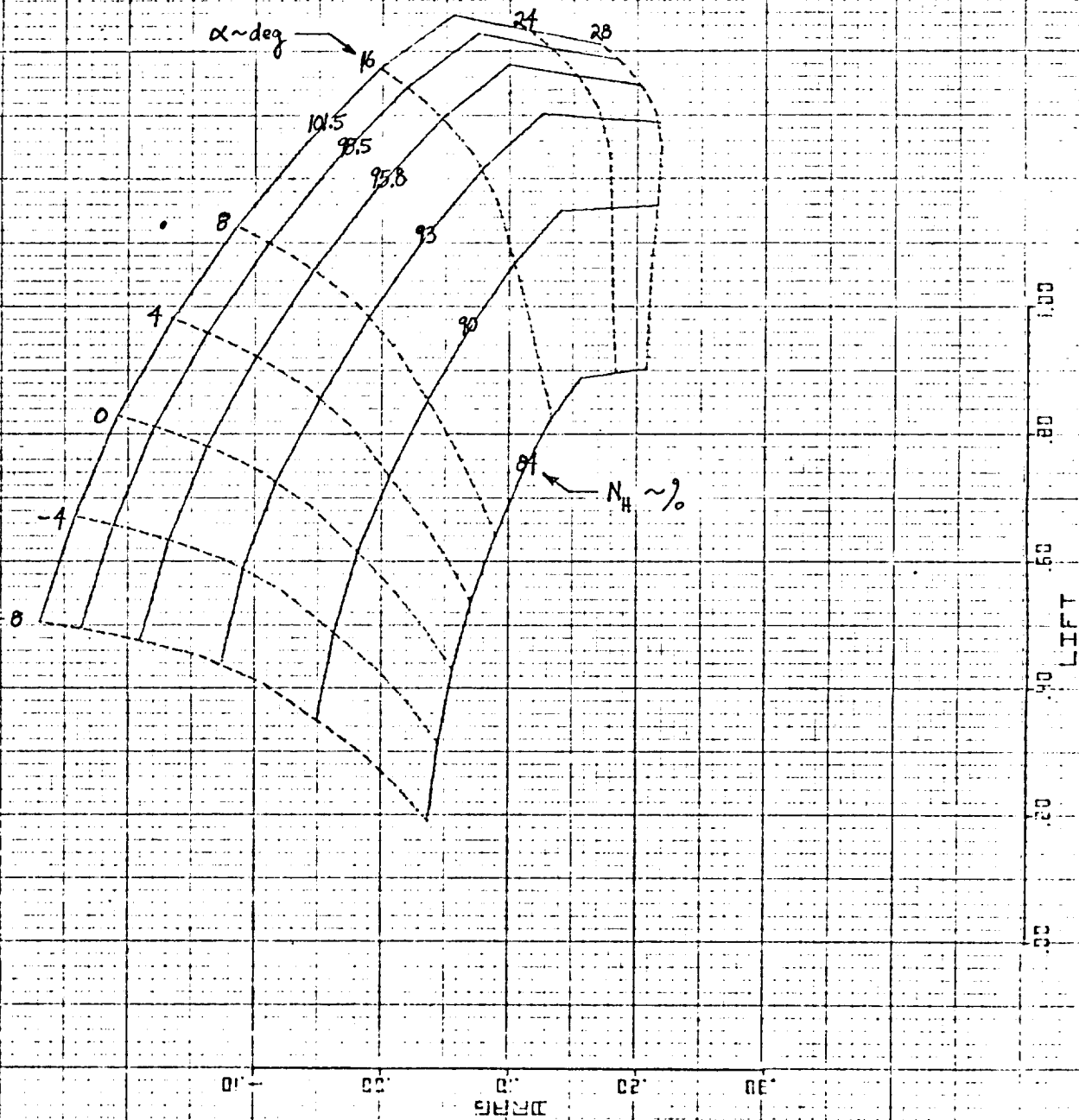
Figure A-5

$V = 65\,KT \quad F = 65° \quad \upsilon = 40°$
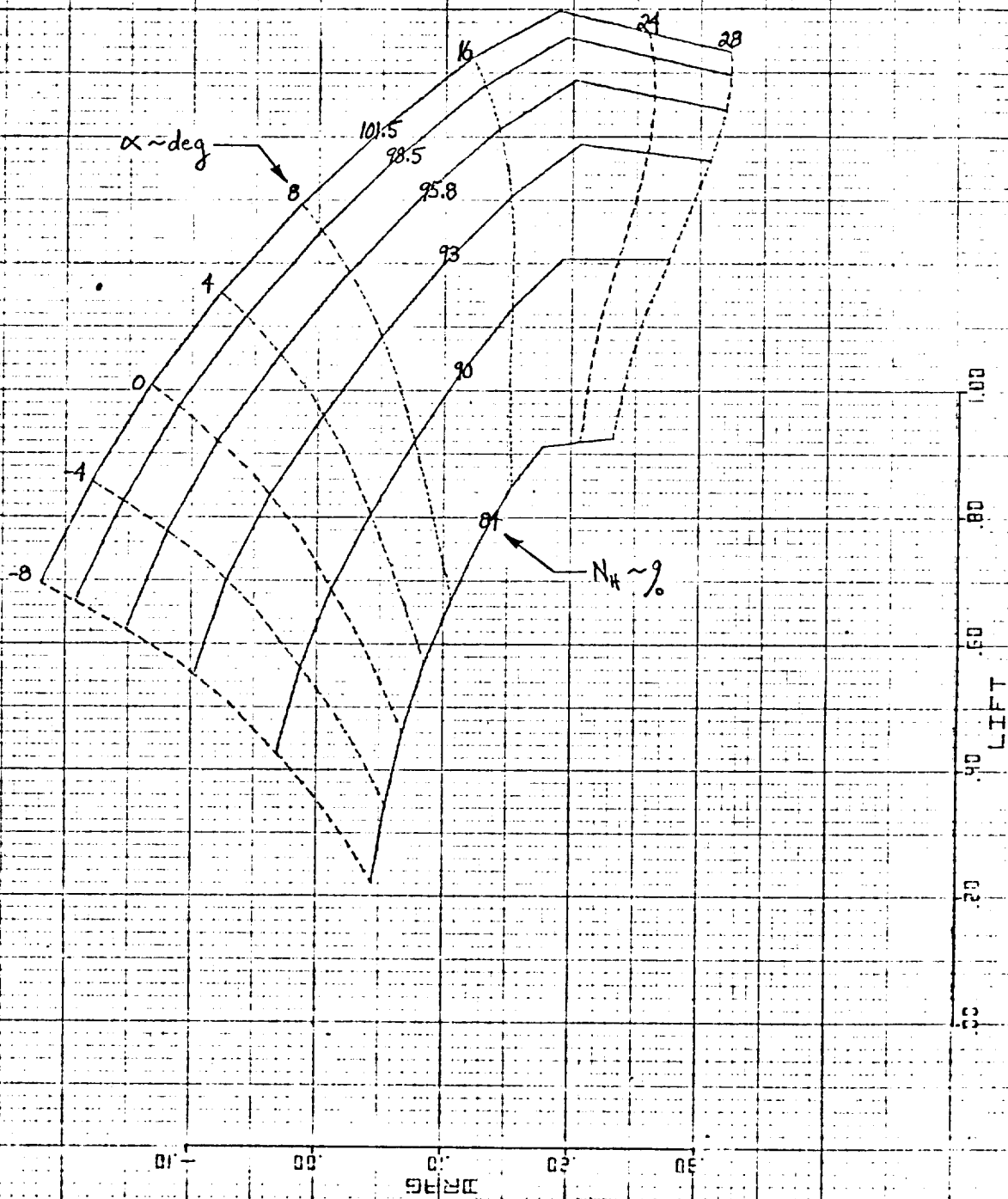
Figure A-6
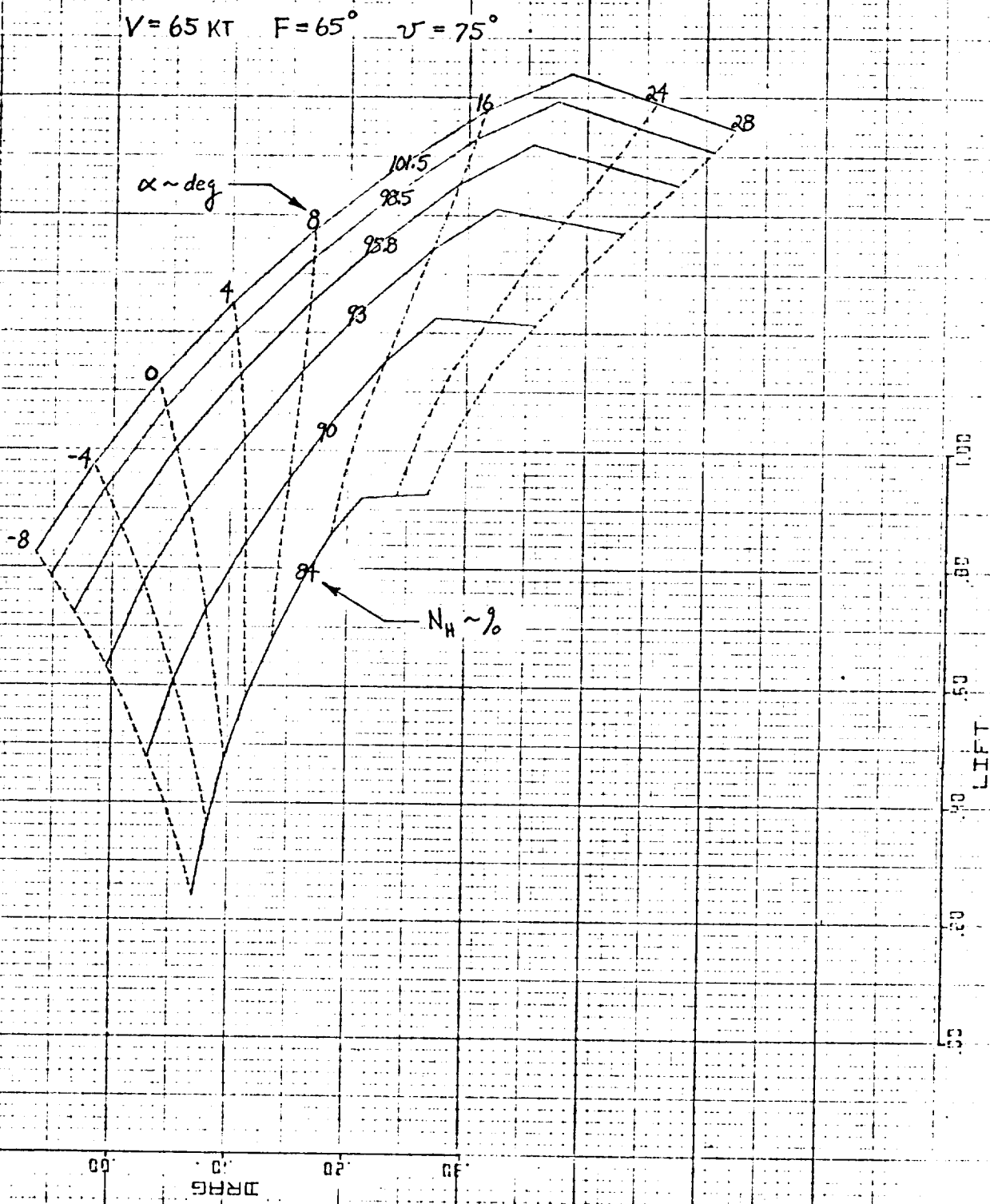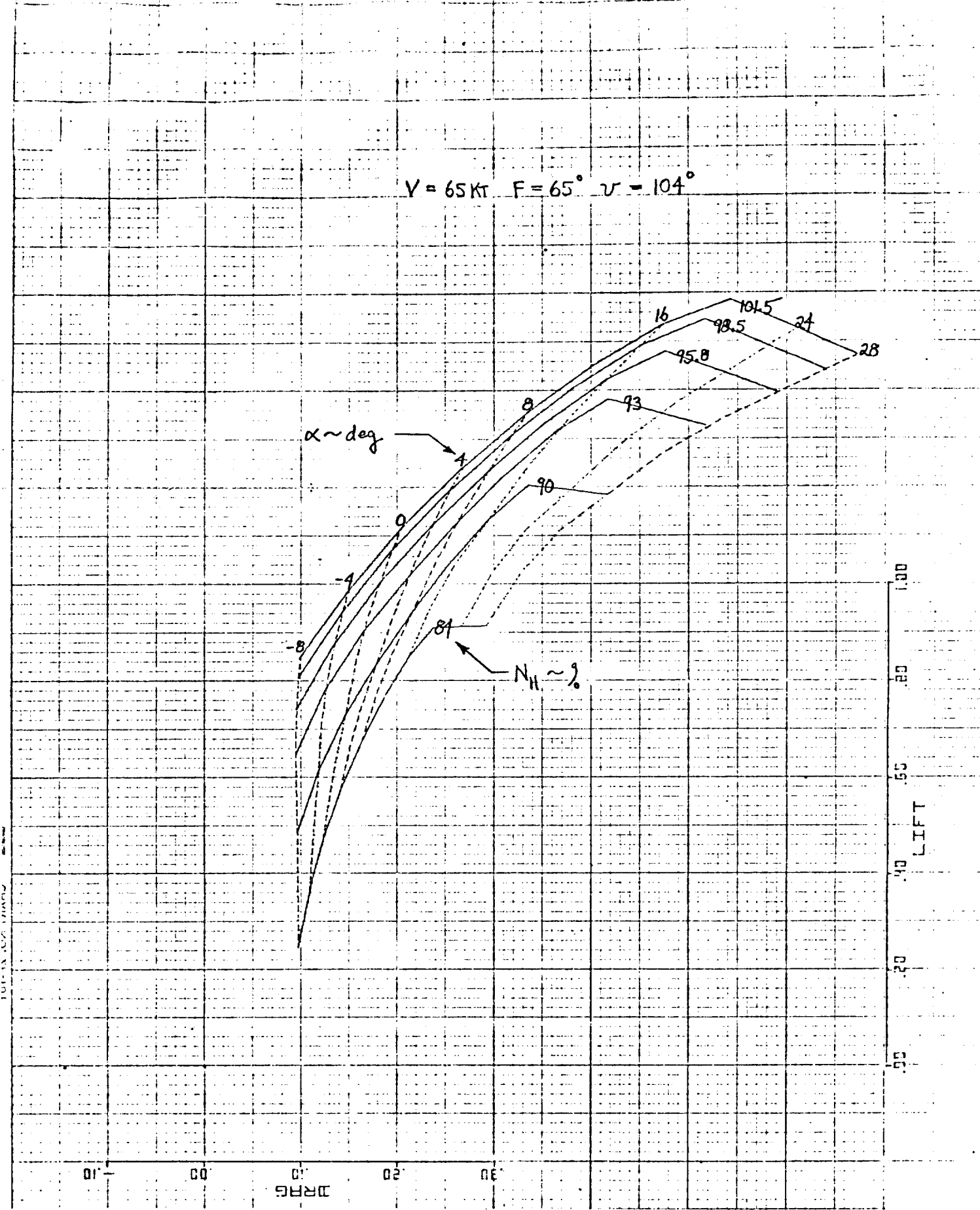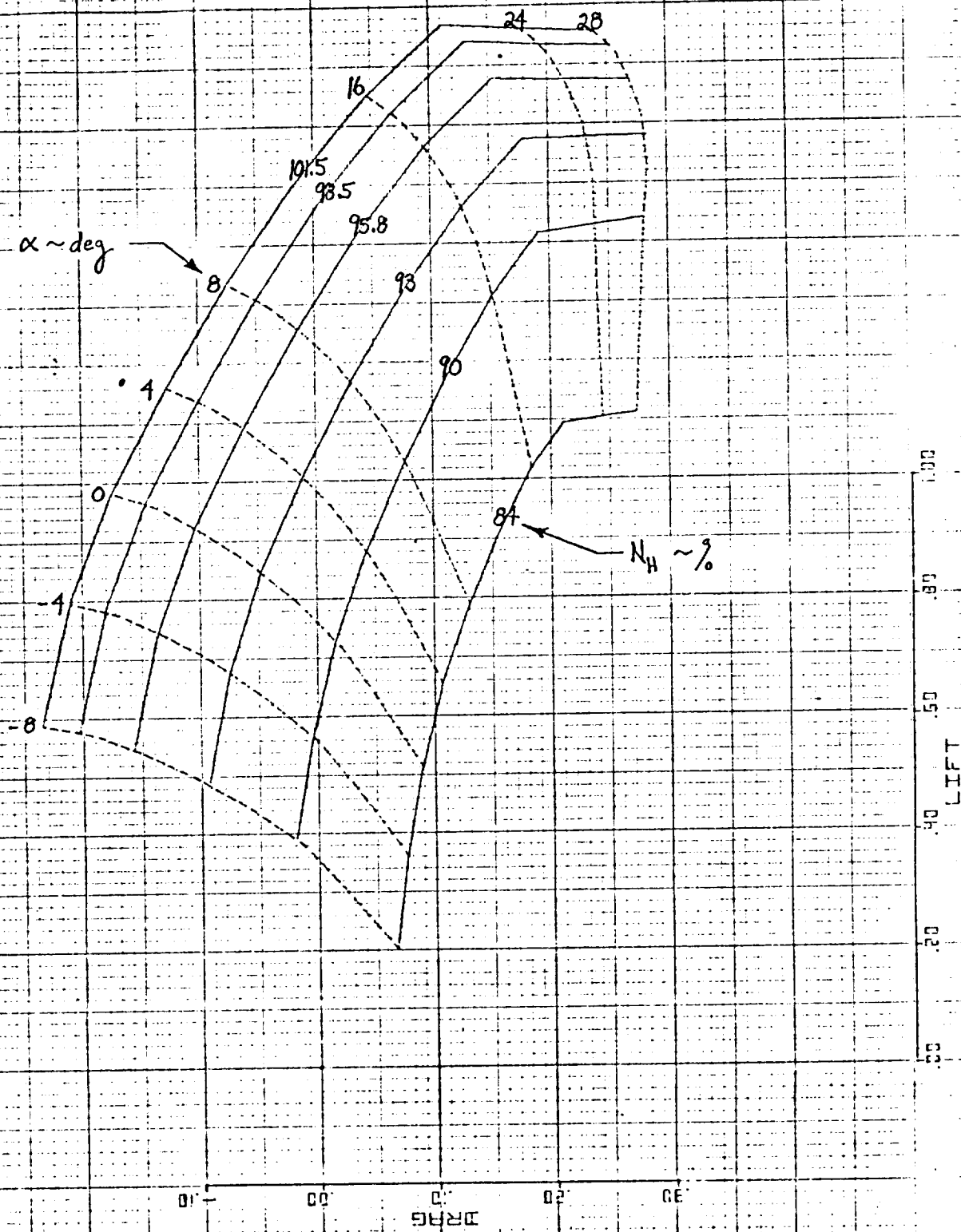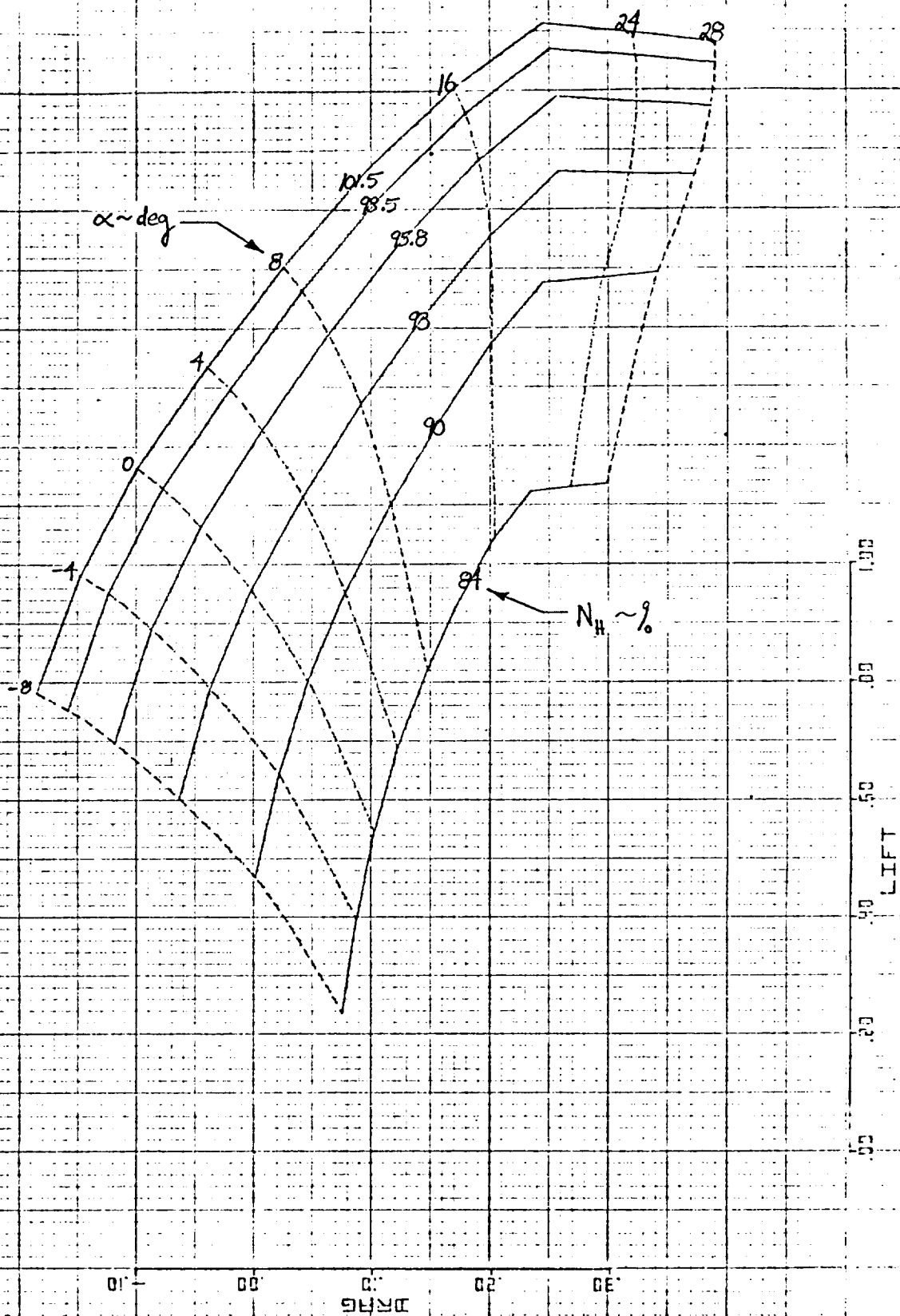
$V = 65$ KT $F = 65°$ $\upsilon = 75°$

Figure A-7

$V = 65 \text{ KT}$ $F = 65°$ $\upsilon = 104°$

Figure A-8

Figure A-9

Figure A-10

V = 75 кт   F = 65°   U = 75°

α~deg

N_H ~ %

Figure A-11

Figure A-12

Figure A-13

$V = 65\,KT \quad F = 50° \quad \upsilon = 40°$

$\alpha \sim deg$

$N_H \sim \%$

LIFT

DRAG
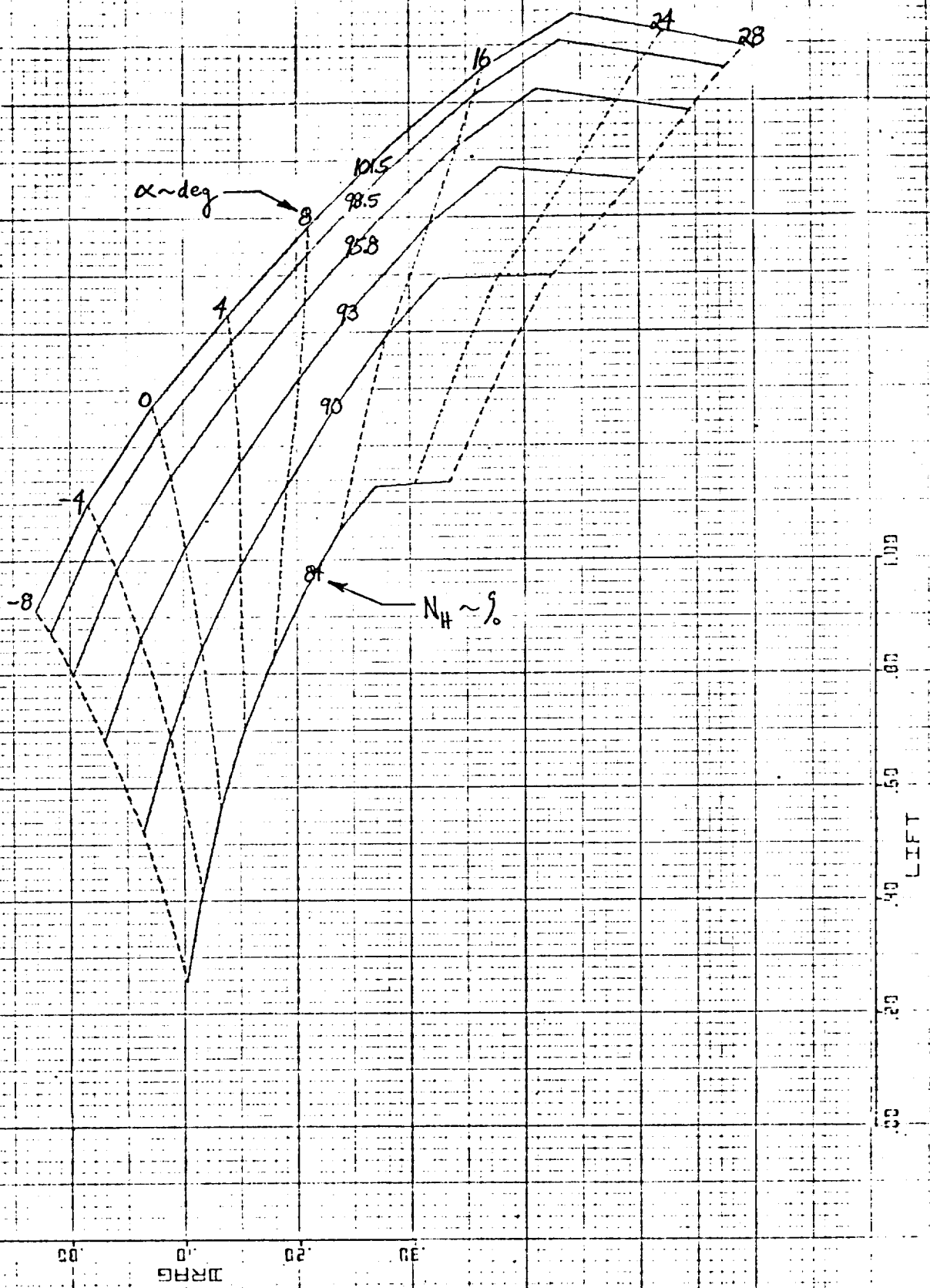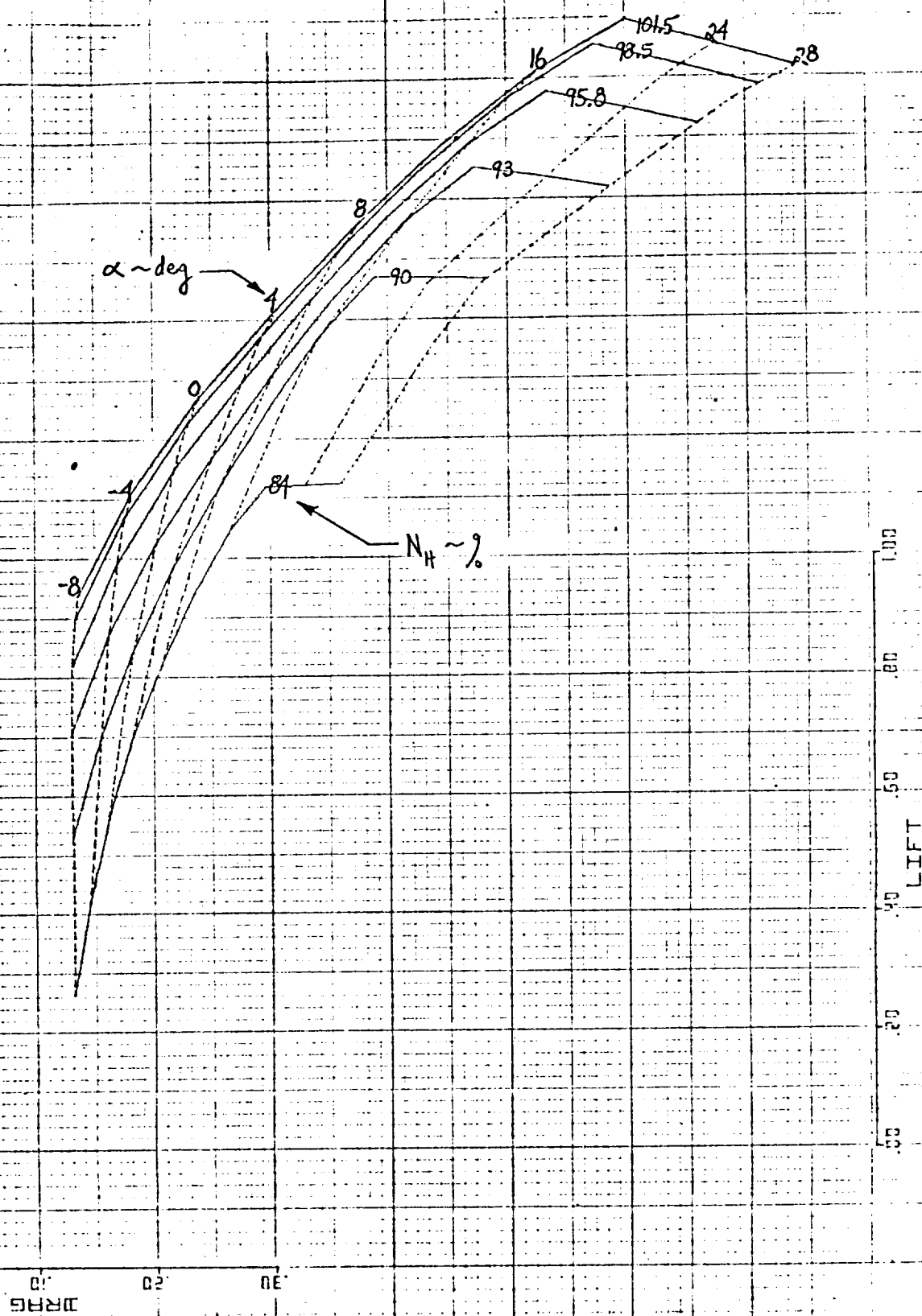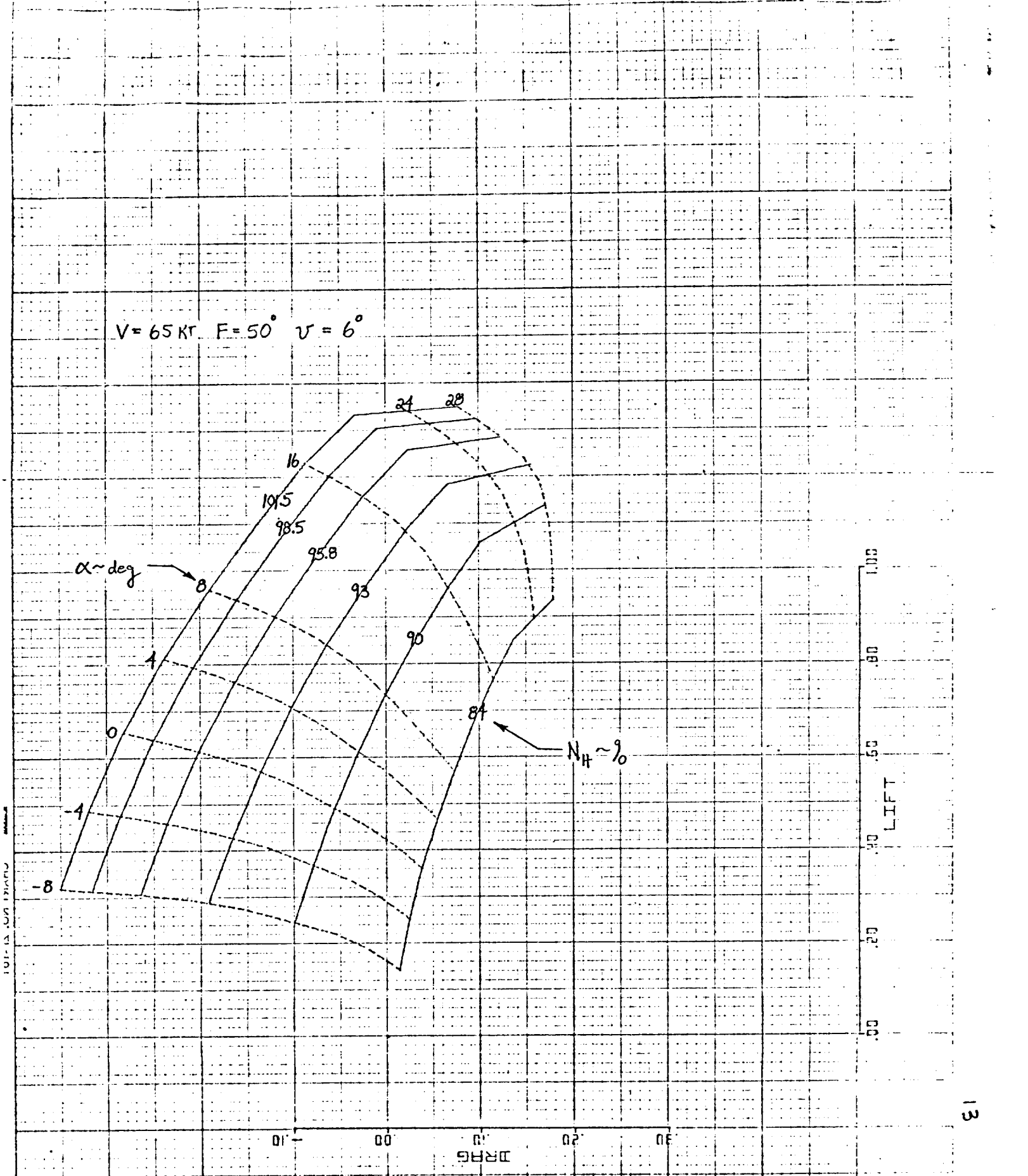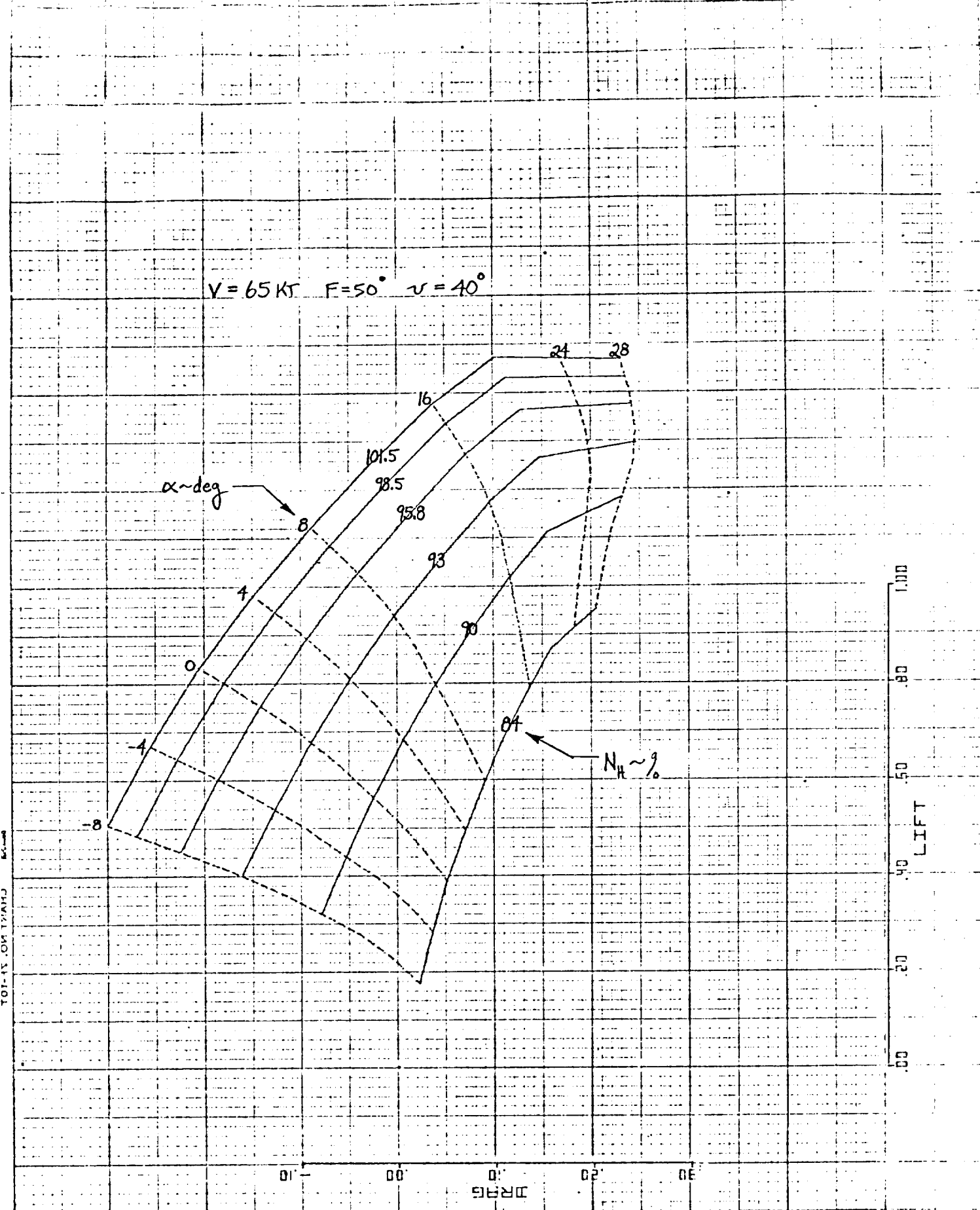
Figure A-14

Figure A-15

$V = 65\,KT \quad F = 50° \quad \tau = 104°$
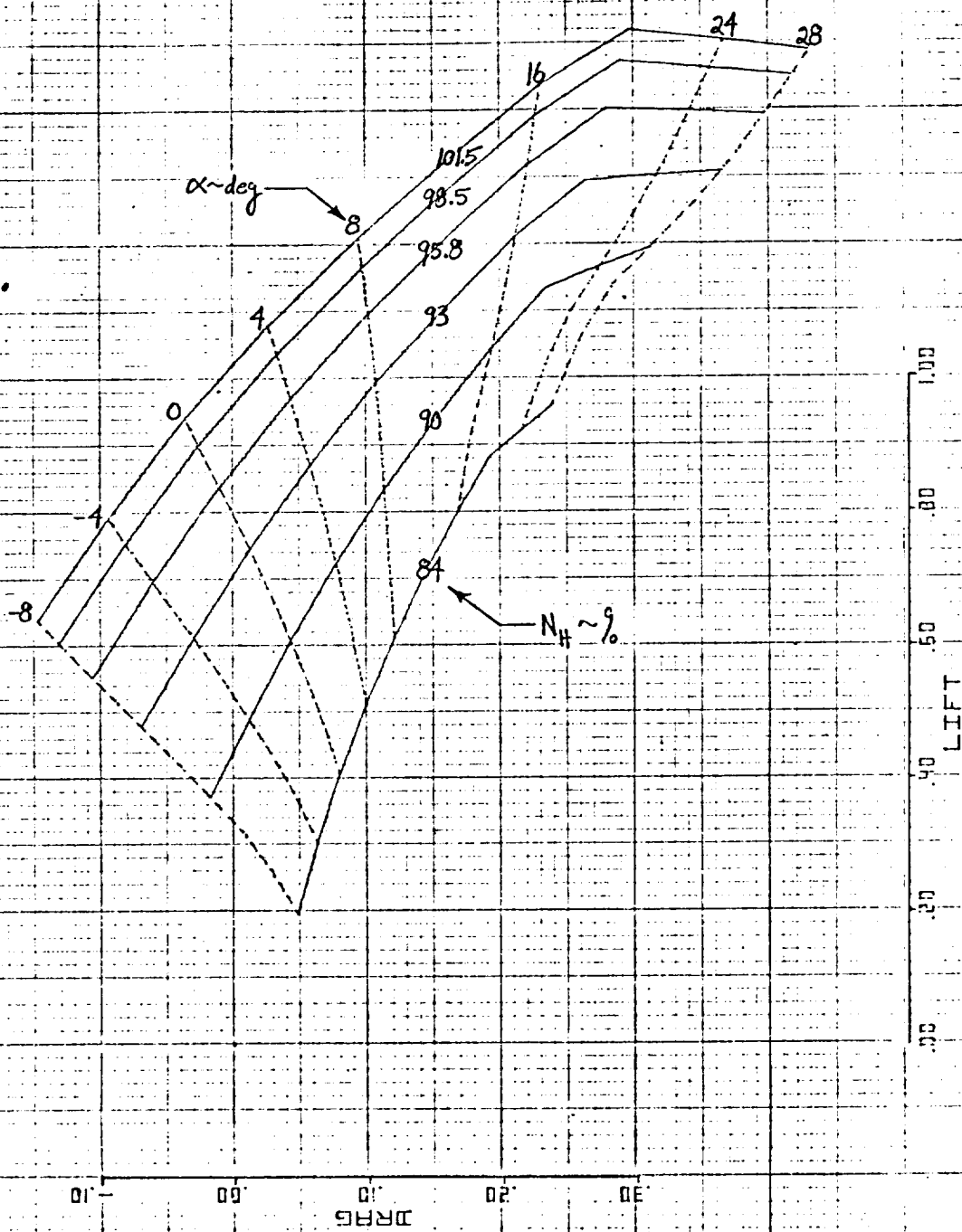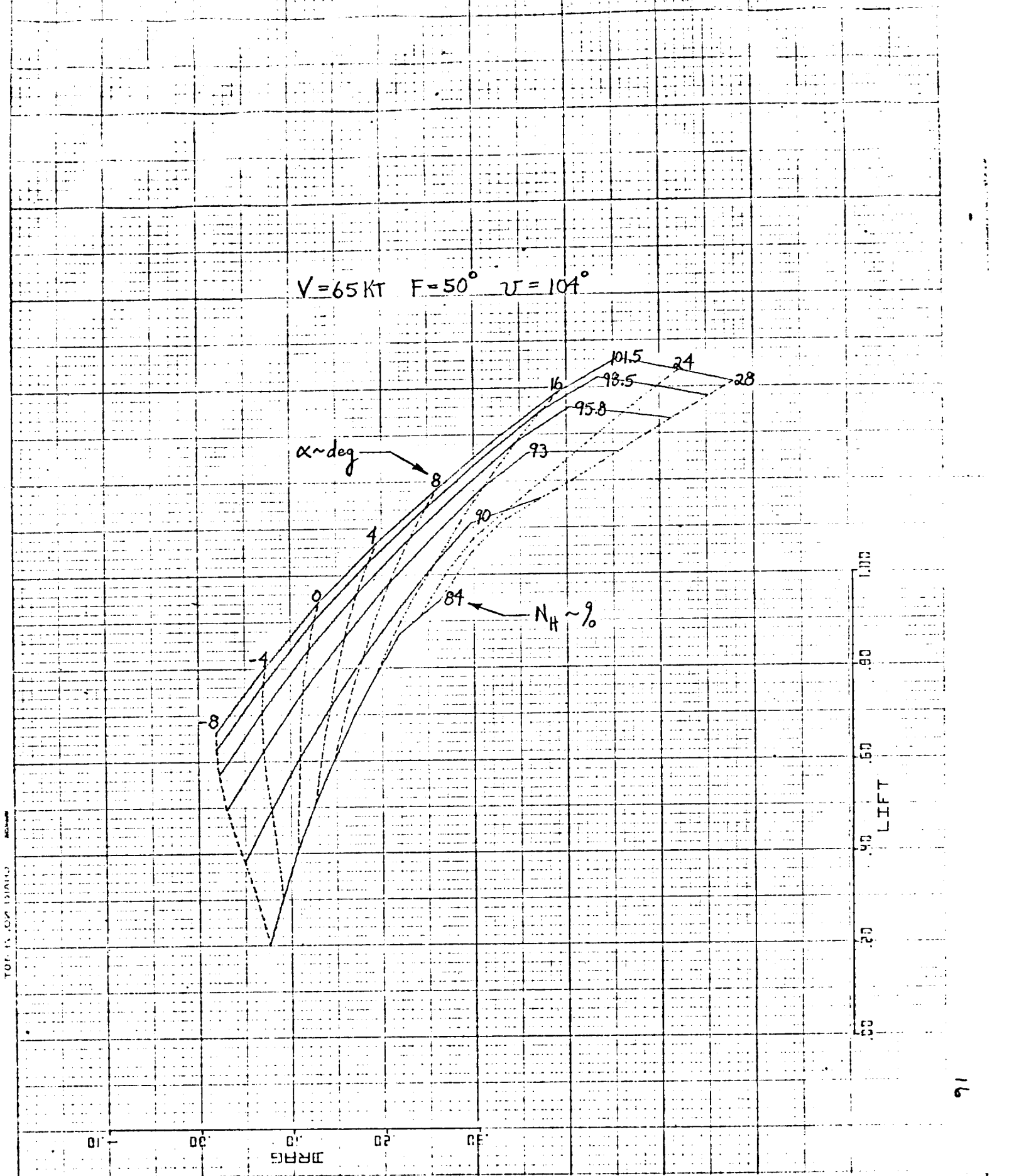
Figure A-16

Figure A-17

$V = 75\,\text{KT} \quad F = 50° \quad \upsilon = 40°$
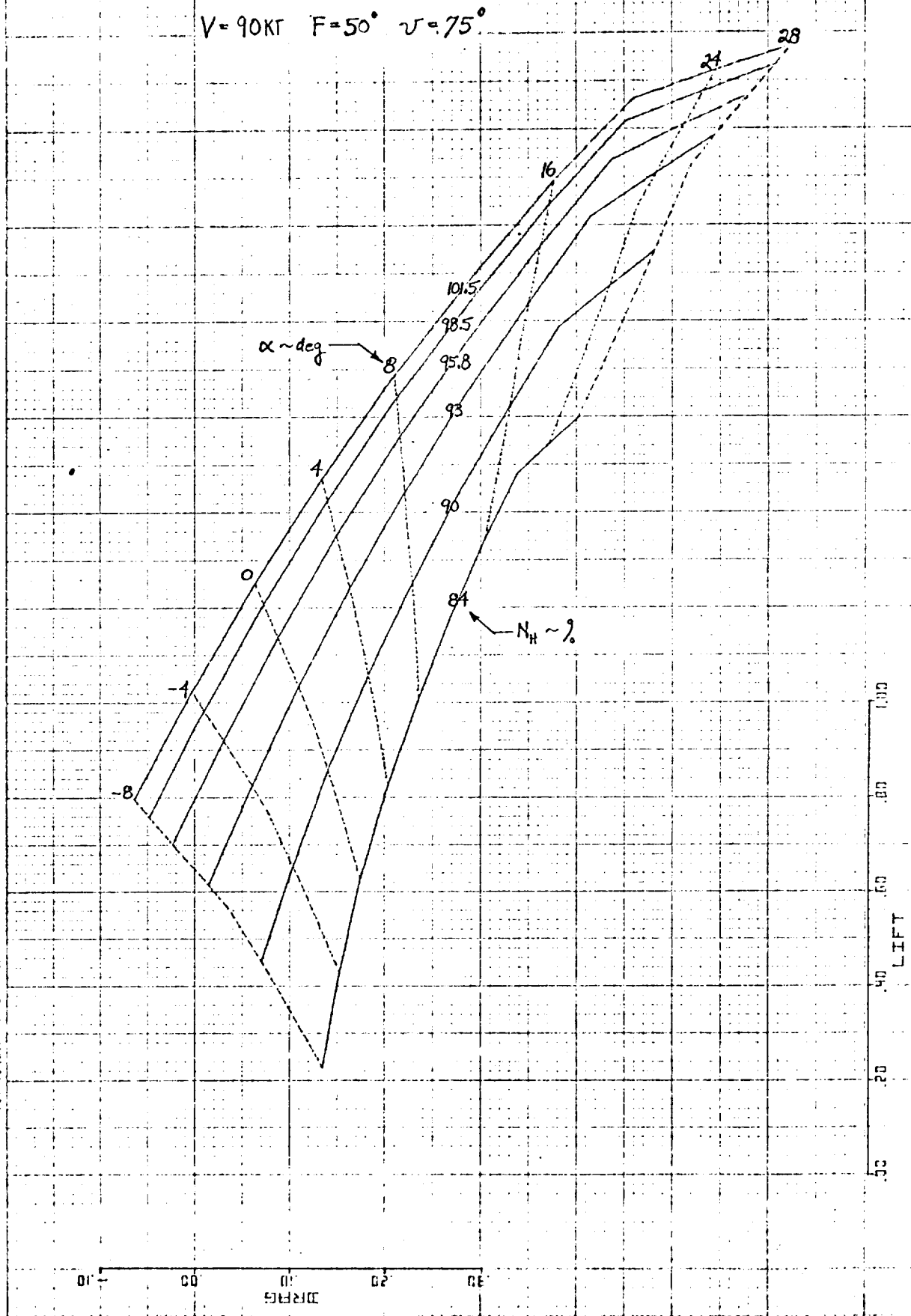
Figure A-18
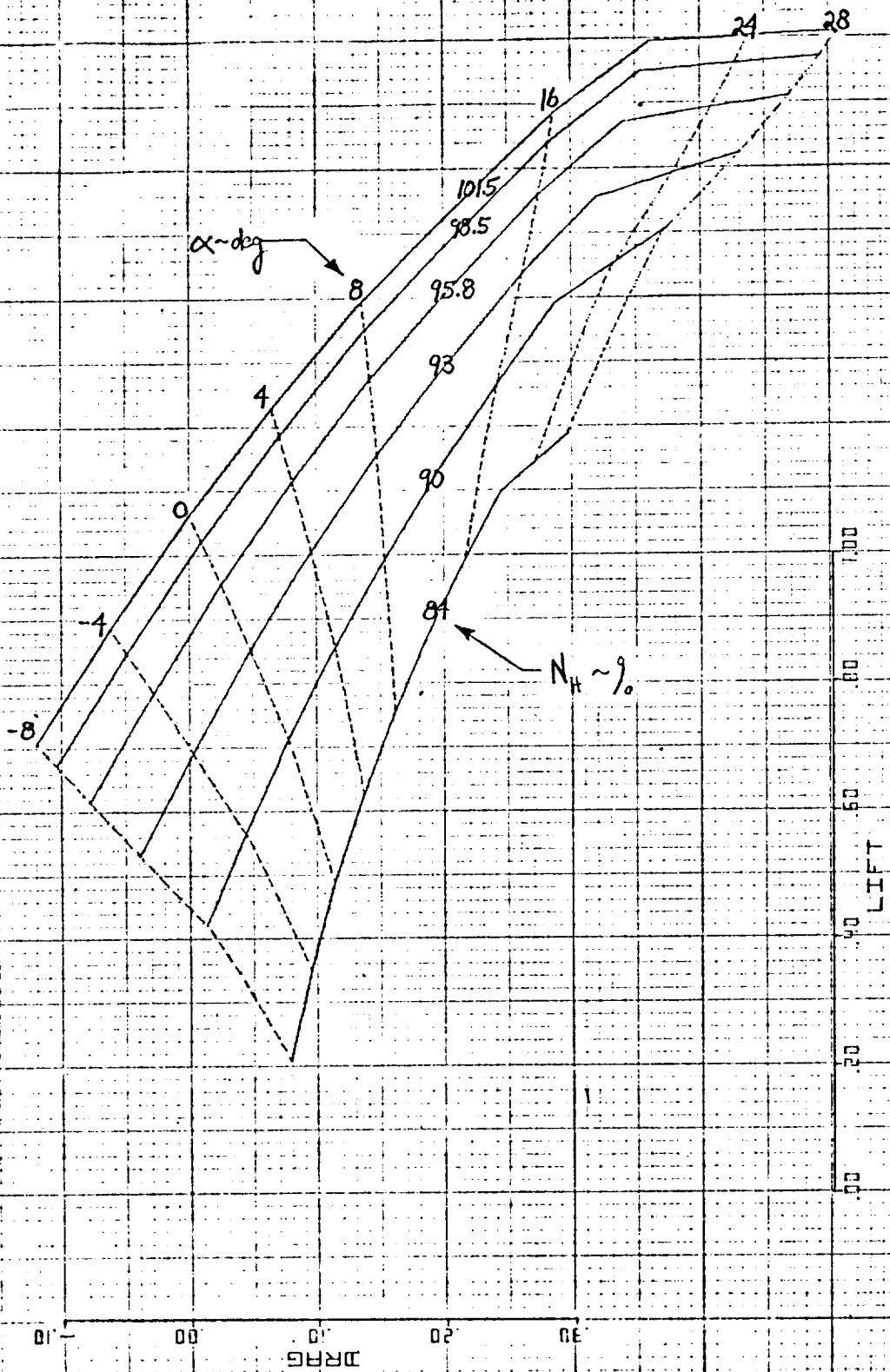
44
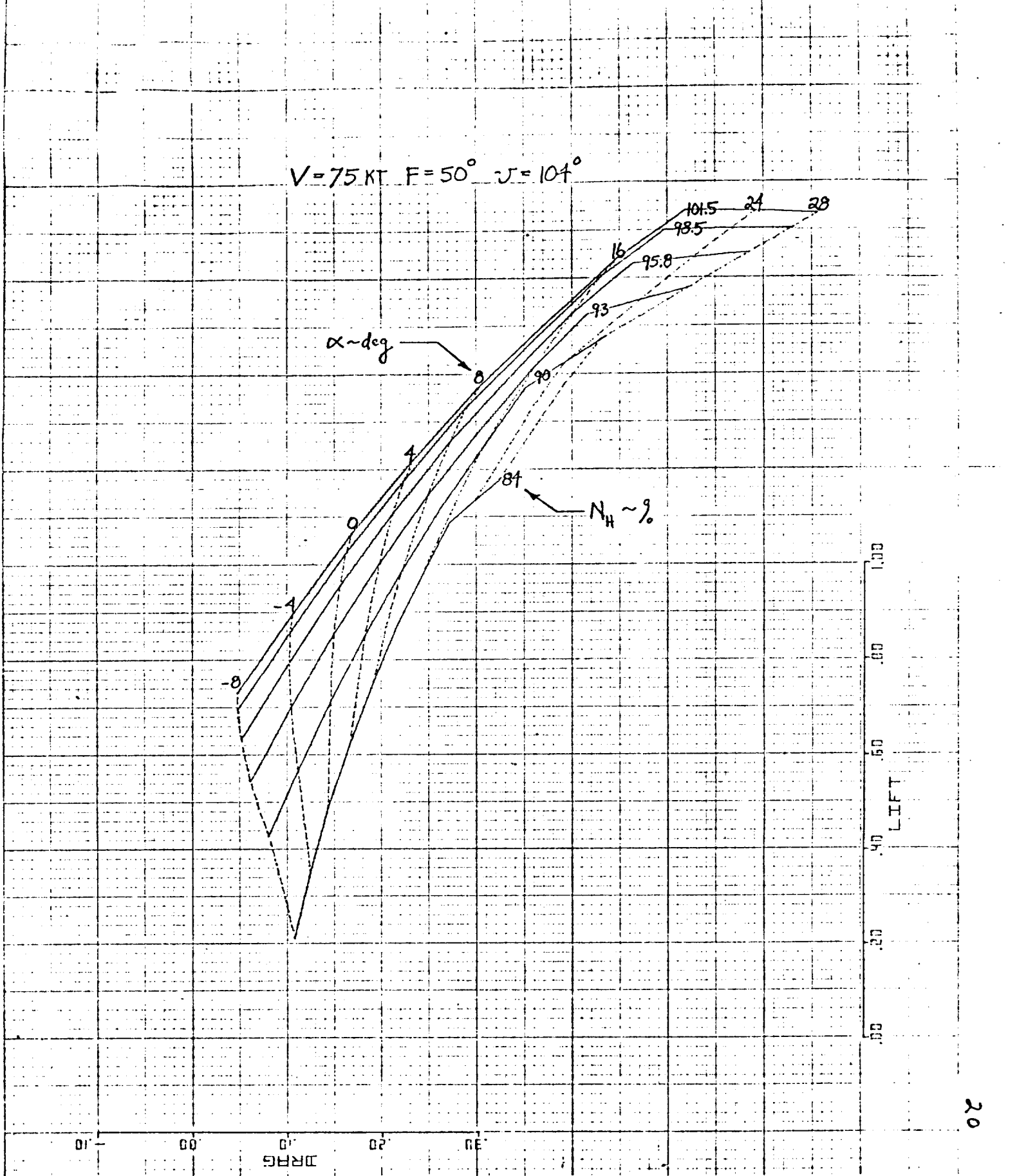
Figure A-19

Figure A-20
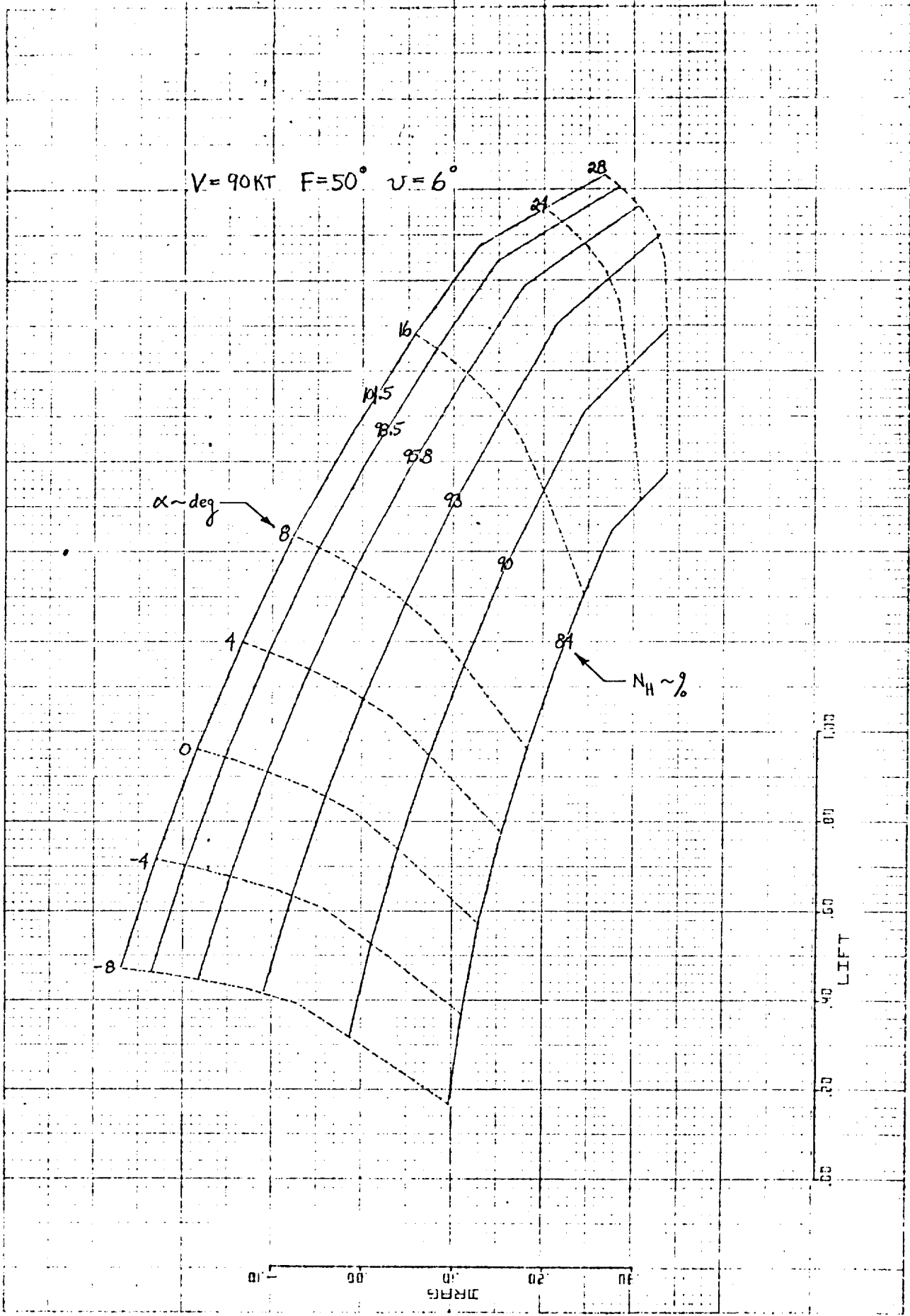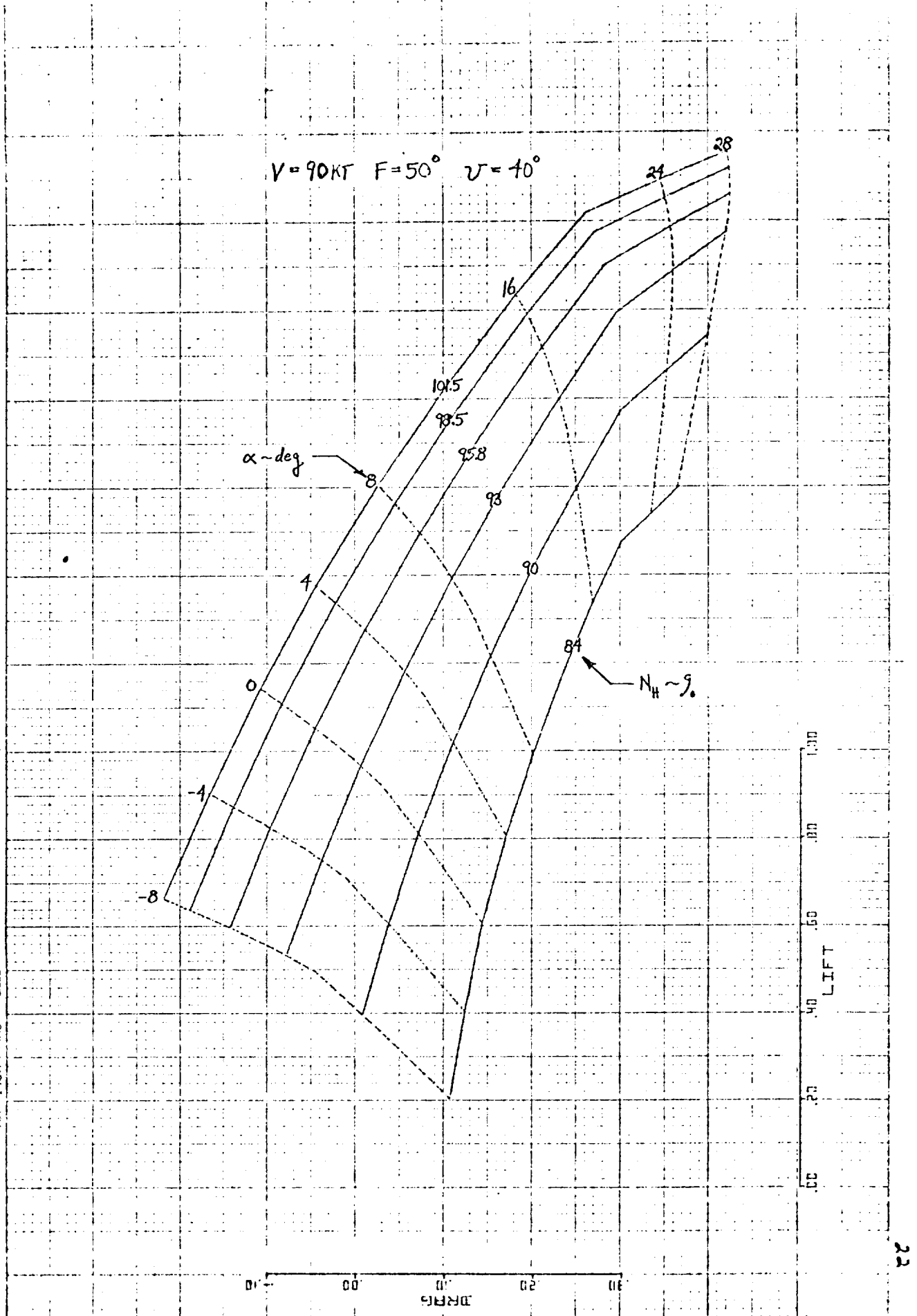
Figure A-21

Figure A-22

Figure A-23

PROJECT SUMMARY

NASA/ARC P.O. R/A 15559B (MV)

SAFETY MARGIN SYSTEM AND DISPLAY CONCEPT FOR
POWERED-LIFT SHORT-HAUL AIRCRAFT FLYING
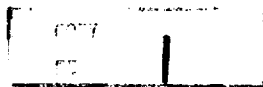IN THE TERMINAL AREA

SYSTEMS TECHNOLOGY, INC.

4 FEBRUARY 1976

Figure 1

DEFINITION OF A SAFETY MARGIN SYSTEM

The functions of the safety margin system are to:

- Provide an indication to the pilot of margins between the current and hazardous vehicle states

- Indicate to the pilot appropriate corrective action when a hazardous vehicle state is encountered

Conversely, the system is not concerned with:

- Trajectory monitoring

- Monitoring the status of on-board equipment, such as the AFCS

Hazardous vehicle states include:

- Those for which a large gust or wind shear could cause a stall, other loss of control, or entry into a region of unknown aerodynamic characteristics

- Those which do not provide adequate performance and maneuverability for normal and emergency maneuvers

- Those which do not provide adequate performance and control for recovery from an engine or AFCS failure

SAFETY MARGIN COMPONENTS

1. LIFT MARGIN

   Provides maneuver capability

   $$LM \overset{\Delta}{=} \frac{L_{max} - L}{W} \quad \text{(change only } \alpha\text{)}$$

   Proposed trim limits:

       0.5 g flaps up

       0.4 g flaps down

2. CLIMB CAPABILITY

   Provides ability to increase γ or accelerate

   Propose $\Delta\gamma$ rather than ΔN_H display

   $\Delta\gamma$ depends on flight reference

   Trim limits $\doteq$ 3-4 deg

3. MAXIMUM FLIGHT PATH

   $\Delta\gamma$ margin does not insure adequate γ_{max}

   PLSDWG proposed $\gamma_{max} \geq 0$

   Not necessary for AW because of nozzles

4. MARGIN FROM α_{max}

α_{max} defined by any hazardous condition

Margin to protect against vertical gusts and attitude abuses

PLSDWG proposed $\alpha_{max} - \alpha > sin^{-1} \; 20/V_{kt}$

α_{max} for AW not firmly established

Appears less restrictive than LM for AW

5. MARGIN FROM V_{min}

V_{min} defined by any hazardous condition or $C_{L_{max}}$

Margin to protect against horizontal gusts and flight reference abuses

PLSDWG proposed:

$V_A \geq 1.15\ V_{min_A}$ and $V_{min_A} + 10$ kt

$V_A \geq 1.3\ V_{min}$ and $V_{min} + 20$ kt

Related to LM because $V_A \geq \sqrt{1 + LM}\ V_{min_A}$

Example for AW:

$N_H = 90\%$, $\delta_F = 65$ deg, $\nu = 75$ deg, $LM = 0.4$

$V_A \doteq 71.5$ kt $\doteq 1.32\ V_{min_A} \doteq V_{min_A} + 17.5$ kt

Less restrictive than LM for AW

6. MARGIN FROM V_{MC}

Less restrictive than LM for AW

7. SPEED MARGIN FOR FCS FAILURE

Could have minimum speed for FCS failure

Not a problem for AW

8. FCS SATURATION

Saturation could drastically alter aircraft dynamics

Not a problem for AW

9. STRUCTURAL LIMITS

Flap placard — handle separately

AW has thrust limit for $\nu > 36$ deg

Thrust limit included in ΔY margin

CONCLUSIONS

- For AW only need lift and ΔY margins
- Lift margin could be flight reference

LIFT MARGIN AS FLIGHT REFERENCE AND
SAFETY MARGIN MONITOR

- Combination reduces pilot workload

- LM is compromise between V and α in terms of (see $\gamma - V$ plots):

  Speed excursions

  γ_{max}
  Control coupling

- Similar flight reference tested in STOL-X simulation

- Should use STOL piloting technique plus N_H or $\Delta\gamma$ crossfeed to nozzle

- Should provide more consistent flares than constant airspeed

- Recovery is so simple recovery display should not be necessary

- STOLAND uses airspeed for flight reference

- Control dynamics were not analyzed

- Need to investigate:

  Display formats
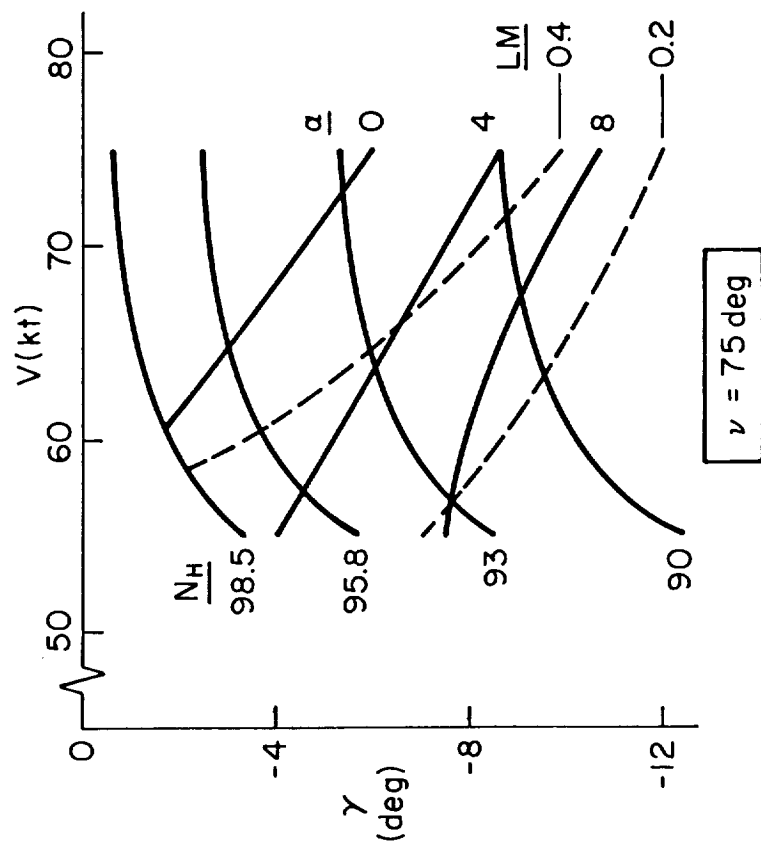
  Need for alerting devices

  Redundancy requirements
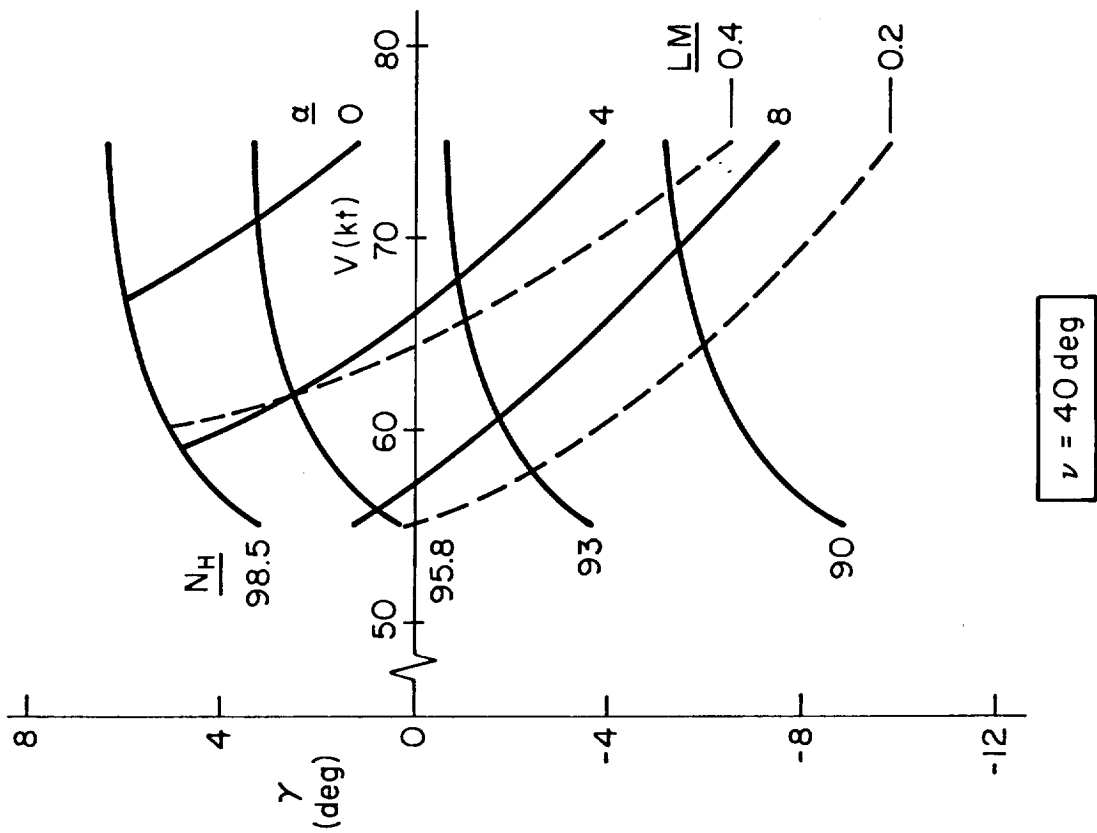
Figure 3. Sample γ-V Curves for the Augmentor Wing

RECOMMENDED FOLLOW-ON PROGRAM

A. MINIMUM PROGRAM

   1. Basic Data

   2. Pilot/Vehicle Analysis

   3. Simulation (2 phases)

   4. Plan Flight Test Program

B. ADDITIONAL WORK ITEMS

   1. Flight Director Design

   2. Flight Envelope Expansion

   3. Mechanization Study

SUMMARY

1. For AW propose:

    • Lift margin as flight reference

    • Lift and ΔY margins as safety margin monitors

2. Concept has great potential. Key to safe powered-lift operations could be use of lift margin instead of airspeed.

3. Follow-on program is necessary to verify potential and work out system details.